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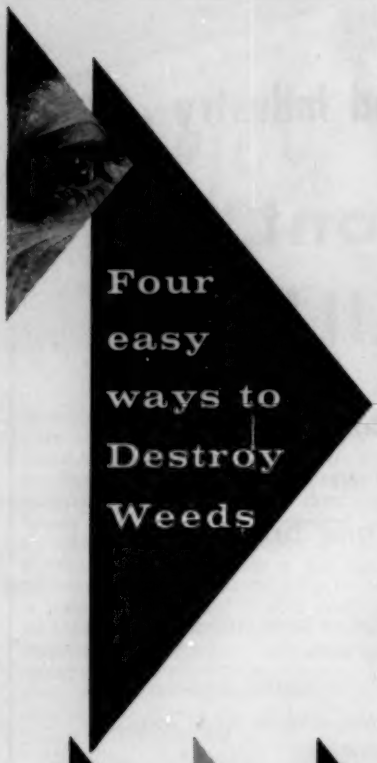

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Weeds

JOURNAL OF THE WEED SOCIETY OF AMERICA

VOLUME 8 APRIL 1960 NUMBER 2

Weed Control in Establishing Birdsfoot Trefoil[1]

H. D. KERR and D. L. KLINGMAN[2]

LACK of seedling vigor is a serious limitation to obtaining adequate stands of birdsfoot trefoil *(Lotus corniculatus* L.). Slow seedling growth makes establishment difficult because competition from weeds or companion crop plants often eliminates the young legume seedlings soon after they emerge. Gist and Mott (4) found that birdsfoot trefoil grows much more slowly than alfalfa and red clover under identical light intensities. Seedlings not eliminated are greatly reduced in size and are susceptible to injury during the winter.

Mowing alone has not been adequate for weed control in birdsfoot trefoil plantings when weed grasses are present in the sward. Repeated mowings will control broadleaved weeds, but the growth of the seedling trefoil may be retarded by such treatment. In addition, mowing releases weed grasses from broadleaved weed competition and allows the grasses to compete critically with the legume seedlings. All weed growth must be controlled if most satisfactory trefoil establishment is to be achieved.

The aim of this study was to compare several mowing and grass-controlling herbicide combinations for weed control in birdsfoot trefoil during the year of planting. Also, a handweeding study to evaluate the effects of separate weed components on trefoil development, and a test of the effect of sodium 2,2–dichloropropionate (dalapon) on the nodulation of trefoil are reported.

LITERATURE REVIEW

The competitive ability of seedling birdsfoot trefoil was studied by Blaser et al. (1). They found that it cannot compete well as a seedling in mixtures with faster germinating species and that it is greatly retarded when planted with one quick germinating grass.

[1]Cooperative investigation of the Crops Research Division, A.R.S., U.S.D.A. and the Missouri Agr. Exp. Sta., Columbia.

[2]Research Agronomists, Crops Research Division, A.R.S., U.S.D.A., formerly at Columbia, Missouri, now located at the Washington Agr. Exp. Sta., Pullman, and the Plant Industry Station, Beltsville, Maryland, respectively.

Scholl and Staniforth (9) reported that an oat companion crop is as detrimental as weed competition on the growth and subsequent yield of trefoil. Smith et al. (11) found that weed growth increases when the seeding rate of an oat companion crop is reduced; therefore, there is little benefit from decreasing seeding rates if weeds are present.

Herbicides are proving their usefulness in controlling weed infestations in trefoil plantings.

In 1953, Klingman (6) found that sodium trichloroacetate (TCA) was more effective for grass control in a new birdsfoot trefoil planting than other herbicides tested. Eight lb/A aeq. of TCA as an early post-emergence treatment gave excellent grass control, retarded growth of smartweed (*Polygonum pennsylvanicum* (L) Small), and caused only slight injury to the birdsfoot trefoil plants. Birdsfoot trefoil is more tolerant to TCA and dalapon than are several other legumes (2,3). Slife (10) compared several herbicides for pre- and post-emergence control of weeds in seedling birdsfoot trefoil and found that:

> "TCA at eight pounds, dalapon at four pounds, sodium 2,2,3–trichloropropionate (2,2,3–TPA) at four pounds, and the alpha–chloro–*N*,*N*–diallylacetamide (CDAA) at four pounds gave comparable results. Grass weeds were well controlled by the pre-emergence treatments—dalapon at the four pound per acre rate was the most effective treatment on grass weeds of the post-emergence herbicides."

McCarty and Sand (7) found TCA, dalapon, and 2,2,3–TPA effective for control of annual grasses in alfalfa plantings. Two pounds of dalapon one week after the alfalfa emerged was an effective grass control treatment. In a second paper, these workers (8) reported that broadleaved weeds were controlled in an alfalfa seeding with 1 pound of 4–(2,4–dichlorophenoxy)butyric acid applied either as a dimethylamine or butyl ester formulation. Kherkin and Peters (5) and Scholl and Staniforth (9) used combination herbicide treatments for controlling both weed grasses and broadleaved weeds in birdsfoot trefoil plantings.

MATERIALS AND METHODS

Field tests. The field studies were on the University of Missouri South Farms on a Mexico silt loam heavily infested with several weeds and forage legumes. Weed grasses consisted mostly of crabgrasses (*Digitaria* spp.), foxtails (*Setaria* spp.), and fall panicgrass (*Panicum dichotomiflorum* Michx.). The crabgrasses were most abundant. Broadleaved weeds in the area were waterhemp (*Acnida* sp.), pigweeds (*Amaranthus* spp.), lambsquarters (*Chenopodium album* L.), Pennsylvania swartweed (*Polygonum pennsylvanicum* (L.) Small), and velvetleaf (*Abutilon theophrasti* Medic.). Legumes that volunteered in the area were Ladino, white, and red clovers (*Trifolium* spp.) and sweetclover (*Melilotus officinalis* (L.) Lam.). Hereafter these volunteer legumes will be considered as a group and

referred to as other legumes. Both broadleaved weeds and grasses were present in thick stand.

The Empire variety of birdsfoot trefoil was planted April 5, 1955 with a conventional drill at 10 pounds of seed per acre. The depth of planting behind the disks was about one-half inch. Excess inoculum was used to promote adequate nodulation. Prior to 1955 the plot area had been planted to corn for silage, and after the silage was harvested in 1954 the area was heavily manured and 4 tons of limestone, ground to pass a 40 mesh screen, applied with 1500 lb/A of rock phosphate. In addition, 250 lb/A of 60% muriate of potash was applied. No nitrogen was applied at planting time.

The herbicide treatments, calculated on the acid equivalent basis, were applied in 40 gpa of water with a compressed air sprayer.

Since dalapon and TCA had previously shown promise for grass control in new birdsfoot trefoil plantings, these herbicides were combined with several mowing and additional herbicide treatments during the seeding year.

The mowing-herbicides combination experiment was a split-plot design in three replicates, with main-plot treatments consisting of 3 pounds of dalapon per acre, 8 pounds of TCA per acre, and an untreated plot, applied May 19, 1955. The seedling birdsfoot trefoil and weed grasses were 3 to 5 inches tall under a canopy of broadleaved weeds 12 inches tall. Mowing and supplemental herbicides were applied to sub-plots in several combinations shown in detail in the tabulated data. Sub-plots were mowed on three dates to a height of 3 to 4 inches.

Stand counts of birdsfoot trefoil plants were made. The weed components were measured by the point method. One hundred points were read per plot with an inclined point quadrat as described by Tinney et al. (12). Data on the control of grasses are given in hits per 100 points, to give a combined estimate of the stand and vigor for treatment comparisons.

Herbage yields were taken in 1956 to further evaluate the 1955 treatment effects on the establishment and vigor of birdsfoot trefoil. A 3 × 27 foot sample was harvested from each 7 × 30 foot plot on three dates during 1956. Harvests were made when the trefoil was one-half to full bloom. The fresh weights were recorded and samples taken for moisture determinations and for hand separation at the first harvest. The composition of the herbage as determined by hand separations agreed sufficiently closely with the mean of three estimates at the first harvest to justify the use of estimations alone at subsequent harvests. Few mean estimates varied more than 10 per cent for major sward components and most estimates were within 5 per cent of the actual percentage based on hand separated samples after oven drying.

A handweeding study was made to evaluate the effects of various weed components on the growth and development of seedling birdsfoot trefoil. The treatments were (1) no weed removal, (2) removal of all weeds, (3) removal of weed grasses, (4) removal of broadleaved weeds, and (5) two applications of 3 pounds of dalapon in combina-

tion with three mowings. Handweeding was done soon after weed emergence when definite removal of all parts of each plant could be effected with least soil disturbance. The number of plants and stems per plant were counted to evaluate the treatments.

Greenhouse test. Effects of dalapon on nodulation of birdsfoot trefoil were studied in a greenhouse test. Rates of 0, 3, 6, and 9 pounds per acre were applied to five replicates on each of five dates. Dates were as follows: (1) 3 weeks before planting, (2) 2 weeks before planting, (3) 1 week before planting, (4) immediately after planting, and (5) 2 weeks after emergence. All planting was done on the same date and uniform watering was practiced. The birdsfoot trefoil was grown in 1 gallon paper cartons filled with 1 part sand, 1 part silt loam. Eight weeks after emergence, the soil was washed from the roots, the nodules per plant were counted, root lengths measured, and oven-dry weights of the roots and tops taken.

RESULTS AND DISCUSSION

Mowing-herbicide combinations. The relative frequency of weed grasses in October and the resulting stands of birdsfoot trefoil are shown in Table 1. Dalapon at 3 pounds per acre was more effective

Table 1. Relative frequency of annual weed grasses in October and birdsfoot trefoil plants per 15 square feet as affected by treatments in 1955.

Sub-plot treatments, 1955[a]				No. grass hits[c] on main plots treated May 19				No. birdsfoot trefoil plants[d] on main plots treated May 19			
Key	May[b] 28	June[b] 18	July[b] 25	Dalapon 3 lb	TCA 8 lb	Check	Av[e]	Dalapon 3 lb	TCA 8 lb	Check	Av[e]
A	M	D	M	0.3	21	79	33	110	106	73	96
B	—	M+D	M	4	14	16	11	110	95	96	100
C	M	M	D	33	116	85	78	100	44	30	58
D	—	M+T	M	3	67	68	46	82	66	56	68
E	M	M	M	76	195	164	145	85	41	15	47
F	—	M	M	110	172	157	146	68	56	53	59
G	—	M	—	66	112	103	94	84	69	67	73
Main-plot mean[e]				42	100	96	—	91	68	56	—

[a]All plots were mowed on August 23, 1955 at a height of 4–6 inches.
[b]D = 3 lb/A of dalapon aeq; T = 12 lb/A of TCA aeq; M = mowed.
[c]Grass contacts per 100 points read were determined by the point method in October.
[d]Trefoil plants in 15 square feet were counted in six ¼ x 3-foot frames in September, 1955.
[e]Least significant differences

	Grass		Trefoil	
	5% level	1% level	5% level	1% level
Main plots	25	41	18	N.S.
Sub-plots	18	25	16	21
Sub-plots in a main plot	32	43	N.S.	N.S.

than 8 pounds of TCA for grass control. Both dalapon and TCA at these rates temporarily retarded the growth of the broadleaved weeds. The TCA treatment retarded grass growth but did not appreciably reduce the stand. In October, when the point readings were made, the weed grasses were equally abundant on the TCA-treated and check plots. McCarty and Sand (7) found that TCA and dalapon are more effective for grass control when applied near the time of grass

emergence. A separate study conducted at this station in 1956 showed that TCA at 8 pounds was equal to 3 pounds of dalapon for grass control when both treatments were applied just after grass emergence. Ninety-five per cent control of weed grasses resulted from both treatments and this lasted for the duration of the dry summer.

Trefoil stands were inversely related to the relative frequency of weed grasses ($r = -.81$, 19 df). Best stands of trefoil were established on main plots treated with 3 pounds of dalapon, because of superior grass control and direct injury to other legume species growing in these plots. There were highly significant differences among the sub-plot treatments. June rains caused a second period of grass germination in 1955 after the early main-plot herbicide treatments had dissipated, and great benefit was derived from supplemental grass control treatments in mid-June, TCA at 12 pounds per acre in June was not as effective as 3 pounds of dalapon for grass control. Treatments in July with 3 pounds of dalapon gave poor grass control in contrast with June applications. The young trefoil had already been retarded by grass competition on the C sub-plots before the July dalapon was applied. On the main-plots given herbicide treatments, sub-plot treatments A and B were about equally effective for grass control. However, in the check plot much better grass control was obtained with the mowing-herbicide combination on the B than on the A sub-plots. Here, mowing on May 28 released weed grasses from broadleaved weeds and allowed them to form a very dense growth, and when 3 pounds of dalapon were applied on June 18 the grasses were so advanced in growth that poorer control resulted than in the unmowed plots. These differences in grass control during 1955 were responsible for big yield differences of birdsfoot trefoil in 1956.

Two mowings were necessary to control broadleaved weeds during the summer when they were used in combination with the better grass-controlling treatments. Dalapon and TCA retarded the growth of pigweeds and smartweed temporarily, but when these herbicides were used in combination with two or more mowings, better weed control resulted. All plots were mowed 4 to 6 inches high on August 23, 1955 as a uniform treatment to permit measuring weed grass control by the inclined-point method in October. This last mowing was not necessary for broadleaved weed control on sub-plots A, B, and D on main plots treated with 3 pounds of dalapon, but it may have been detrimental to the birdsfoot trefoil.

These plots were harvested thrice in 1956 for herbage yield determinations. Harvested material was separated into four component groups and total main-plot yields are shown in Table 2. Significant differences among main plots were apparent in the yields of trefoil. The more vigorous trefoil stands established on main plots treated with 3 pounds of dalapon in 1955 resulted in greater yields than on the other main plots. Differences were not significant among main plots in total herbage, other legumes, or weed component yields. Although weed grasses and other legumes tended to yield less on the dalapon-treated main plots, there was such diversity among the species present that the lack of one was compensated for by others.

Table 2. Pounds of ovendry herbage per acre in 1956 as affected by main-plot treatment the previous year.

Sward component	Herbage, lb/A from main plots treated May 19, 1955			LSD 5%
	Dalapon 3 lb	TCA 8 lb	Check	
Birdsfoot trefoil	1890	1040	640	710
Other legumes[a]	3700	3840	4420	N.S.
Annual weed grasses	1450	2000	1720	N.S.
Annual broadleaved weeds	1080	930	840	N.S.
Total	8120	7810	7620	N.S.

[a]Legumes other than birdsfoot trefoil that volunteered in the area were white, red, and Ladino clovers, and sweetclover.

Volunteer legumes made the herbage yield data difficult to interpret solely in terms of birdsfoot trefoil yields that resulted from weed control. In fact, other legumes as a group produced more herbage than birdsfoot trefoil did on many plots. Trefoil yields were negatively correlated with other legume yields ($r = -.68$, 19 df).

Annual weeds were abundant in the area and reinfestation of all plots occurred in a random pattern in 1956. Herbage production by weeds in 1956 was independent of weed stands in 1955 because the mowings in 1955 largely prevented seed production. Broadleaved weed yields were inversely related to the total yield of the remaining components ($r = -.48$, 19 df). Weed grass yields did not show a similar relationship.

Sub-plot yields are presented in Table 3. Differences among sub-plots in the total yields or in the yield of weed grasses were not significant, but there were differences among the yields of the other three components. Broadleaved weeds produced a higher percentage of herbage on C sub-plots, because poor grass control in 1955 prevented satisfactory trefoil establishment and the July dalapon application was particularly injurious to *Trifolium* species in these

Table 3. Ovendry herbage per acre in 1956 from sub-plots given treatments supplemental to main-plot treatments applied May 19, 1955.[a]

Sub-plot treatments, 1955				Component yields in pounds per acre				
Key	May[b] 28	June[b] 18	July[b] 23	Birdsfoot trefoil	Other legumes	Annual weed grasses	Annual blvd. weeds	Total
A	M	D	M	2590	3400	1590	860	8440
B	—	M+D	M	2410	3260	1540	880	8090
C	M	M	D	940	3540	1880	1460	7820
D	—	M+T	M	1350	3700	1980	800	7830
E	M	M	M	500	4470	1480	1000	7450
F	—	M	M	240	4300	2080	820	7440
G	—	M	—	310	5230	1530	830	7900
LSD 5%				440	840	N.S.	350	N.S.
LSD 1%				590	1130	N.S.	470	N.S.

[a]Main-plot treatments were 3 lb/A aeq of dalapon; 8 lb/A aeq TCA; and a check. All plots were mowed 4–6 inches high August 23, 1955.
[b]D = 3 lb of aeq of dalapon; T = 12 lb aeq TCA; and M = mowed 3–4 inches high.

sub-plots. Consequently, broadleaved weeds met with less competition on C sub-plots in 1956. Other legumes tended to yield less on sub-plots given herbicide treatments for grass control in June or July 1955 because of some direct injury from the herbicide treatments, and because the better trefoil stands established in these sub-plots offered more competition to the other legumes in 1956.

Trefoil yields alone are shown in Table 4. Yields in 1956 were directly related to the stands of trefoil established the previous year which in turn were related to weed control, weed grasses in particu-

Table 4. Ovendry birdsfoot trefoil herbage per acre in 1956 as affected by 1955 weed control treatments.[a]

Sub-plot treatments, 1955				Birdsfoot trefoil yields, lb/A, main plots, treated May 19, 1955[a]			
Key	May[b] 28	June[b] 18	July[b] 23	Dalapon 3 lb	TCA 8 lb	Check	Av
A	M	D	M	3860	3140	760	2590
B	—	M+D	M	2860	2080	2310	2420
C	M	M	D	2320	370	120	940
D	—	M+T	M	2150	940	970	1350
E	M	M	M	1130	290	80	500
F	—	M	M	340	240	140	240
G	—	M	—	610	220	100	310
Main-plot mean[c]				1890	1040	640	

[a] All plots were mowed August 23, 1955.
[b] D = 3 lb/A aeq of dalapon; T = 12 lb/A aeq of TCA; and M = mowed at 3–4 inch height.
[c] Least significant differences

	5% level	1% level
Main plots	710	N.S.
Sub-plots	450	600
Sub-plots in a main plot	770	1030

lar. The combination of two 3-pound dalapon applications and three mowings during 1955 (treatment A in dalapon treated main plots) resulted in 3860 pounds of ovendry trefoil herbage per acre. The timing of the mowing and dalapon treatments in 1955 was important, since sub-plot B with the same number of mowings and identical dalapon treatments yielded only 2860 pounds per acre. The only difference was that sub-plot A was mowed about 3 weeks earlier than B. However, in the check main plots which received no dalapon in May, the highest yield of trefoil came from sub-plot B. Here, earlier mowing in 1955 released the grasses that competed strongly with the seedling trefoil. It was important to control grasses early, as well as mow moderately early for control of broadleaved weeds, for most successful trefoil establishment.

Effects of separate weed components on birdsfoot trefoil development. Effects of several weeding treatments on the stand and stem development of birdsfoot trefoil are shown in Table 5. The data are means of three replicates. Drought conditions after planting caused poor emergence of trefoil in 1956 and thus stands were rather poor. However, for comparative purposes this experiment yielded usable data. The initial stand averaged about two plants per square foot, and this stand was maintained only on plots kept free of all weeds. When all weeds were removed from plots, the number of stems per

Table 5. Stand and stem development of birdsfoot trefoil as affected by various weed control treatments.[a]

Weeding treatments	Trefoil plants per 15 sq ft	Number of stems	
		In 15 sq ft	Per plant
Removal of broadleaved weeds	1.7	2.3	1.4
No weed removal	7.3	9.7	1.3
Removal of weed grasses	20.7	32.7	1.6
Dalapon + 3 mowings[b]	21.3	46.7	2.2
Removal of all weeds	35.6	366.7	10.3
LSD 5%	8.4	52.2	—
LSD 1%	12.2	76.0	—

[a]The birdsfoot trefoil was planted April 4 and harvested in September 1956. Only a sparse stand of birdsfoot trefoil was obtained because of drought conditions at the time of seeding.
[b]This consisted of two dalapon applications at 3 lb/A and 3 mowings during the summer of 1956; a duplication of treatment A of Table 4.

plant was about ten-fold that on plots having no weeds removed. The dry weight yield of trefoil (not shown in Table 5) was over five hundred times as great on weed-free plots as on plots having no weeds removed. If weed grasses were removed, over 12 times as many birdsfoot trefoil plants survived as on plots freed of broadleaved weeds. Two 3-pound dalapon treatments plus 3 mowings controlled both weed grasses and broadleaved weeds, but mowing retarded birdsfoot trefoil growth compared with that on weed-free plots, and gave stands equal to those in plots having weed grasses removed by hand. It gave

Figure 1. Development of birdsfoot trefoil grown in the greenhouse as affected by (1) no treatment, (72) 6 lb/A dalapon, and (48) 9 lb/A dalapon applied 2 weeks after emergence. The 6-pound treatment 2 weeks after emergence had no appreciable effect on the tops, roots, or stands of birdsfoot trefoil, while 9 pounds reduced stands about 30 percent and stunted the growth. Nodulation of roots was proportional to the growth.

almost 5 times as many stems as the plots having no weeds removed and 1.4 times as many as in plots having grasses removed.

Effects of dalapon on nodulation of birdsfoot trefoil. Root systems of birdsfoot trefoil plants growing in field plots treated with 6 pounds of dalapon had an abundance of normal-appearing nodules. However, it was decided to perform a detailed study in the greenhouse to check on nodulation. Of the three rates of dalapon treatment on five dates only the 9 pounds of dalapon applied three weeks after planting in a greenhouse experiment resulted in adverse plant response. About one-third of the plants were killed and the foliage of the live plants was severely damaged. However, all live plants were nodulated and the nodules appeared normal as to size and color in comparison with those on untreated plants. Plants surviving the 9 pounds of dalapon were smaller and had fewer nodules per plant than those treated with lower rates (Figure 1). However, it was evident that decreases in number of nodules were related to the smaller plants resulting from the 9-pound treatment rather than any direct effect of the herbicide on nodulation (Figure 2). The root system of every live trefoil plant in the study had normal-appearing nodules and the number was closely related to the weight of the roots of individual plants. Also, the number per plant was directly related to the ovendry weight of the corresponding tops, with a correlation

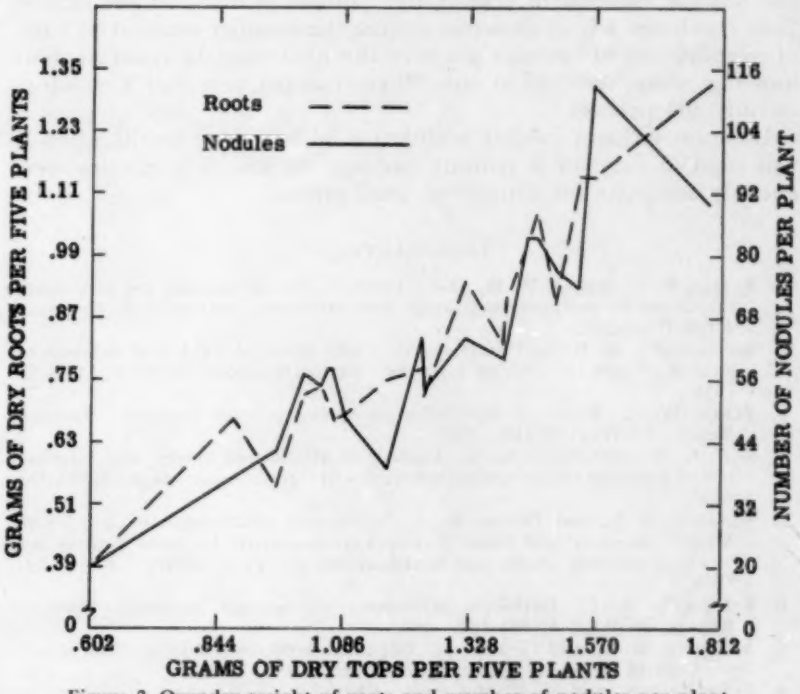

Figure 2. Ovendry weight of roots and number of nodules per plant as related to corresponding top weights.

coefficient of 0.86 (18 df). Similarly, the coefficient for the root weights and the corresponding top weights was 0.94.

SUMMARY

Mowing alone and in combination with dalapon and TCA was studied for weed control and effect on establishment and growth of birdsfoot trefoil. The effects of separate weed components on stand and stem development of seedling birdsfoot trefoil were evaluated in a handweeding study. Nodulation of birdsfoot trefoil as affected by several rates of dalapon was studied in the field and in a greenhouse test.

Mowing alone was not adequate for weed control in birdsfoot trefoil because it removed the canopy of broadleaved weeds which reduced the competition and released the weed grasses allowing them to compete with the birdsfoot trefoil seedlings. In a handweeding study, weed grasses alone were more detrimental to the growth and development of birdsfoot trefoil than broadleaved weeds alone or weed grasses and broadleaved weeds combined.

An application of 3 pounds of dalapon in mid-May followed by mowing 2 weeks later, a second 3-pound dalapon treatment a month later, and 2 more mowings resulted in about 2 tons of birdsfoot trefoil hay the subsequent year. Three pounds of dalapon per acre in June combined with 3 mowings during the summer resulted in 1 ton of ovendry trefoil herbage per acre the next year. In contrast, four mowings alone resulted in only 80 pounds per acre and 3 mowings in only 100 pounds.

Dalapon did not inhibit nodulation of birdsfoot trefoil when it was used at rates of 6 pounds per acre or less. These rates were entirely adequate for control of weed grasses.

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Effects of Monuron on Halogeton and Associated Salt-Desert Shrub Vegetation[1]

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HALOGETON *(Halogeton glomeratus)* is an introduced, poisonous annual plant which is rapidly invading the salt-desert ranges of western North America (6). The poisonous constituent of this plant is water-soluble oxalic acid, which varies from 17 to more than 30 percent of the dry weight in its leaves during the growing season.[3] Because of the poisonous property of halogeton and its dense population on disturbed site, it is of considerable importance to the livestock industry (1, 2, 3, 8, 12).

The borrow pits of highways in the Great Basin usually have a large population of halogeton. (The borrow pits are drainage areas immediately adjacent to the road shoulders and the soil used to build up the roadbed is "borrowed" from these pits.) The additional moisture derived from drainage of the roadbed substantially increases the vigor and densities of these populations. Halogeton is a prolific seed producer. Germination, establishment and survival studies indicate that an inch of seed-producing stem can potentially produce from 3 to 39 plants during the following growing season. These calculations are based on the potential of the "black seeds." Data on the germination of "brown seed" (5, 12, 13, 14) and the establishment and survival of their seedlings are not available.

The disturbed and denuded soils of livestock and game trails, railroad rights-of-way, and highway rights-of-way have provided some of the major avenues by which halogeton has spread into new habitats. Highway rights-of-way are probably one of the more important routes to new infestations because of the profusion of both "brown seeds" and "black seeds" in and on the soil of the borrow pits and man's intense use of roads and the immediately adjacent areas (6, 11).

Sterilization of the soil surface appeared to have promise as a means for reducing the spread of the weed. Available data indicate that embryos which escape from the seed coat below a depth of ¼ inch do not emerge from the soil. The vegetation bordering the borrow pit is often weak in vigor or reduced in density to a degree that halogeton can invade. Therefore, closing of highway rights-of-way as a pathway of incursion by halogeton necessitates sterilization of the soil surface under the adjacent perennial vegetation until vigor and density of the vegetation would prevent the growth and development of invading plants. Soil sterilization under the perennial vegetation would not accomplish its purpose in the event it

[1]Cooperative investigations of the Crops Research Division, A.R.S., U.S.D.A. and the Utah Agr. Exp. Sta.

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[3]From unpublished data of M. C. Williams.

weakened or destroyed existing perennial vegetation (4). The herbicide 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron)[4] was selected for this study because of its relatively slow movement in heavy soils under low rainfall (7, 9, 10). The sites selected for this study were along Utah Highway 70, which is graded but not surfaced. The soil is silt loam, and the average rainfall from site to site ranges from 6 to 9 inches per year.

Plots were laid out to encompass 1 square rod of the perennial vegetation at the edge of the borrow pit and ½ square rod of the borrow pit. The plots were 1 rod wide. Monuron was applied at rates of 8, 4, 1, 1, ½ and 0 (control) pounds active ingredient per acre. These rates were replicated three times in each of the three plant communities studied. The individual plant communities selected for this study were stands of big sagebrush *(Artemisia tridentata)*, black sagebrush *(Artemisia nova)*, and a community of shadscale *(Atriplex confertifolia)* containing scattered plants of bud sage *(Artemisia spinescens)*.

Monuron was applied in November 1952 and permanent transects were established. The clumps intersected through their basal area by the two diagonal transects were counted on that date and during the late summer of 1953, 1954, and 1955. Widening of the highway in the spring of 1956 prevented further studies of the plots. It was necessary to make an additional visit during the spring of each year to make accurate counts of the bud sage because of its caducous leaf habit.

The portion of the plots in the borrow pit was occupied exclusively by halogeton while the rest of the plots were occupied by perennial vegetation. The response of these two classes of plants over the period of study was so diverse that it is desirable to report the data from the plots according to the type of vegetation originally occupying the two portions of each plot.

Tables 1 and 2 contain summaries of the data from the portion of the plots originally occupied by the perennial vegetation. The results from the portion of the plots in the borrow pit will be discussed later in the text.

The "number" column in each table contains categories to describe the number of plants per square rod as obtained by visual estimations. These categories are as follows: uncommon = 1 to 5 plants; sparse = 6 to 20 plants; few = 20 to 100 plants; many = 100 to 1,000 plants; abundant = 1,000 to 5,000 plants; and very abundant = 5,000 to 30,000 plants.

It can be observed in the tables that there was a reduction of perennial shrubs and an increase in the number of halogeton plants with increased rates of monuron applied. The relationships between the rate of monuron, the survival of perennials, and number of halogeton plants continued through 1954 and 1955 with the exception of plots

[4]The author wishes to acknowledge the cooperation of the E. I. du Pont de Nemours & Co. (Inc.), Grasselli Chemicals Department, Wilmington, Del. in supplying the compound used in this experiment.

Table 1. Survival of big sagebrush and black sagebrush, and of halogeton in stands of each, in untreated plots and plots treated with monuron in 1952. Average of three replications.

Monuron lb/A	Survival of big sagebrush percent	Estimated number of halogeton plants in big sagebrush stand	Survival of black sagebrush percent	Estimated number of halogeton plants in black sagebrush stand
		1953		
0	94.1	few	100.0	none
½	85.2	few	79.4	many
1	66.7	few	65.2	many
2	46.7	many	51.8	abundant
4	19.0	many	19.0	abundant
8	00.0	none	42.0	uncommon
		1954		
0	100.0	few	100.0	none
½	85.2	few	81.0	many
1	51.9	many	66.7	many
2	46.7	many	53.6	abundant
4	13.0	very abundant	16.0	very abundant
8	6.7	very abundant	3.7	very abundant
		1955		
0	105.9	none	100.0	none
½	85.2	few	81.0	many
1	51.9	many	66.7	many
2	30.0	abundant	53.6	very abundant
4	10.0	very abundant	1.6	very abundant
8	00.0	very abundant	1.8	very abundant

Table 2. Survival of shadscale, bud sage, and halogeton in untreated plots and plots treated with monuron in 1952 in shadscale community. Average of three replications.

Monuron lb/A	Survival of shadscale percent	Survival of bud sage percent	Estimated number of halogeton plants
	1953		
0	90.0	100.0	sparse
½	75.0	75.0	many
1	52.8	66.7	abundant
2	54.3	66.7	abundant
4	27.0	53.9	very abundant
8	39.0	26.3	uncommon
	1954		
0	101.0	100.0	uncommon
½	75.0	87.5	many
1	52.8	66.7	abundant
2	45.7	70.0	very abundant
4	27.0	53.9	very abundant
8	00.0	26.3	very abundant
	1955		
0	104.0	92.7	uncommon
½	72.5	87.5	many
1	52.8	66.7	abundant
2	45.7	70.0	very abundant
4	00.0	53.9	very abundant
8	00.0	31.6	very abundant

that had been treated with 8 lb/A. There was a total of 9 plots treated at the 8 lb/A rate and only 2 halogeton plants were found on these plots during 1953; however, in 1954 and 1955 these plots contained the largest populations of halogeton of any of the plots in this study.

During 1954 and 1955, rabbitbrush *(Chrysothamnus visidiflorus* subsp. *stenophyllus)* invaded the plots in the stand of black sagebrush and in the shadscale community treated at the three higher rates. Plots treated with the 2 lb/A rate averaged about one plant per plot, at 4 lb/A the plots averaged over 2 plants per plot, while the 8 lb/A rate resulted in the invasion of 3 to 5 rabbitbrush plants per plot. Rabbitbrush is not known to be poisonous, but since it is rather unpalatable there is little reason to recommend it as a substitute for halogeton.

On the segments of the plots in the disturbed soil of the borrow pit, the 8 lb/A rate of monuron prevented growth of halogeton during the growing season of 1953. At rates of 4 lb/A and lower, no visual differences could be noted between the treated and control plots in the density or vigor of the halogeton stand. In 1954 and 1955 all treated plots, including the 8 lb/A plots, had approximately the same density of halogeton population as the control plots.

When results from both sections of the plots, i.e., the segments in the borrow pit and the portions occupied by perennial vegetation, are considered together, it becomes obvious that at least 8 lb/A of monuron are required to obtain a substantial reduction in the halogeton population on sites similar to those included in the study. It is also apparent that the increase in the halogeton population on the part of the plots originally occupied by perennial vegetation was a response to the reduction in perennial plants rather than applications of monuron at rates of ½, 1, 2, and 4 lb/A.

A study of the distribution of the root systems of a few plants was carried out during the growing season of 1958. Information obtained from this study helps explain the results secured in the sterilization study. Big sagebrush, shadscale, and perennial kochia *(Kochia americana)* have extensive lateral root systems undulating from ½ to 1½ inches below the soil surface. Mature halogeton plants studied had no lateral roots above 3 inches, and generally lateral roots were first encountered 5 to 8 inches below the soil surface. The author has transplanted seedlings from the field to the greenhouse over the past 6 years and has observed that seedlings do not have lateral roots within 2 inches of the surface.

The writer has observed that while an application of 8 lb/A of monuron effectively kills germinating seeds on the surface of the soil the lighter applications do not. That monuron is leached to a depth of at least ½ inch is evidenced by the toxic effect on the perennial vegetation with all rates of application. Preliminary data (unpublished) indicate that very light applications of monuron (2 lb/A) placed 4 inches beneath the soil surface are lethal to growing halogeton and do not appear to injure perennial shrubs. Evidence accumulated to date indicates that root distribution may be an important

factor in obtaining selective control of weeds with nonselective soil sterilants.

SUMMARY AND CONCLUSIONS

Monuron applications of 2, 4, and 8 lb/A resulted in permanent reductions of the perennial shrubs. The halogeton population was substantially reduced for one season by 8 lb/A. Rabbitbrush and halogeton both invaded plots on which the more desirable shrubs had been killed.

Control of halogeton by the use of nonselective soil sterilants should be undertaken with caution, especially where big sagebrush, black sagebrush, shadscale, and perennial kochia are important components of the plant community. The surface root system of these shrubs will probably absorb chemicals applied to the soil surface long before they are leached into the soil horizons occupied by halogeton roots. Since halogeton is the most prevalent pioneer plant in the areas which it now infests, any reduction in the perennial vegetation can only result in more area suitable for the invader.

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Cytological Effects of Herbicidal Substituted Phenols[1]

GABRIELE N. MÜHLING, J. VAN'T HOF, G. B. WILSON, and B. H. GRIGSBY[2]

A LARGE proportion of the commonly used herbicidal substances were derived from that class of organic compounds somewhat loosely known as the substituted phenols. Many of these compounds, as well as their close relatives, have been reported to affect cell division in a number of ways. Since there appeared to be some confusion as to the type or types of effect as well as to the similarities between the effects of different members of the group, comparative studies of a number of compounds were undertaken. Two questions were considered: 1. are the cytological effects such as to suggest subtle biological hazards to organisms apparently not affected morphologically; and 2. is there a family resemblance in the cytological reaction category? Although neither question has been answered satisfactorily, the results of our studies to date are sufficiently suggestive to warrant reporting.

METHODS AND MATERIALS

The method used was essentially that reported by Bowen and Wilson (2). Pea seeds (*Pisum sativum* var. Alaska) were soaked in Pyrex distilled water overnight and then rolled in paper toweling to germinate for 48 hours at 25° C. Seedlings having a primary root of 2.5 to 3 cm. in length were suspended by waxed, wire mesh above a 250 ml. beaker containing ¼ strength Hoagland's balanced nutrient salt solution. The chemical to be tested was added to the balanced salt solution in appropriate concentrations. Carbowax 1500, which has no effect on either growth or cell division, was used as a solvent for chemicals not water soluble. All chemicals were tested at a minimum of four concentrations.

Forty to 60 pea seedlings were treated continuously for 8 to 12 hours at 22.5° C. Samples of five seedlings were removed from the treatment beaker at designated time intervals, the primary roots were fixed in three parts ethanol and one part glacial acetic acid fixative, and finally stained by the Feulgen Method. All analyses were made from squash preparations of root meristem.

When treatment was completed, the remaining seedlings were washed and either transferred to a beaker containing balanced salt solution, or rolled in paper toweling to recover from treatment. Such seedlings are referred to as recovered seedlings.

Each experiment was accompanied by a control which was maintained continuously in balanced salt solution.

[1]This work was carried out with the aid of funds supplied by the Michigan Agr. Exp. Sta., Jour. Art. No. 2426.

[2]Research Instructor, Graduate Assistant, Professor of Botany, and Professor of Botany, respectively, of the Department of Botany and Plant Pathology, Michigan State Univ., East Lansing. The authors are indebted to Mr. P. G. Coleman for the preparation of the photomicrographs.

Two hundred dividing cells per sample, 600 to 1,000 dividing cells per time interval, were counted to determine effect.

Table 1 gives a list of the chemicals which have been tested sufficiently to warrant inclusion. The 2,4–dinitrophenol, 2,4–DNP, which appeared to have much in common with the herbicides, has been used as a standard since many of its physiological effects are reasonably well known.

Table 1. Cytological effects of herbicides.

Chemical name	Commercial name or text designation	Lowest concentration level for cytological effect	Colchicine reaction	Reaction prophase poison	Inhibits (onset) of cell division
2,4-dichlorophenol	none	60 ppm (3.7×10^{-4}M)	+	±	+
2,4-dichlorophenoxy-ethanol	none	180 ppm (8.69×10^{-4}M)	+	?	+
2,4-dichlorophenoxy-acetic acid	2,4-D	40 ppm (1.84×10^{-4}M)	+	+	+
2,3,4-trichlorophenoxy-acetic acid	2,3,4-TA	60 ppm (2.36×10^{-4}M)	+	?	+
2,4,6-trichlorophenoxy-acetic acid	2,4,6-TA	375 ppm (1.48×10^{-3}M)	+	?	+
2,4-dichlorophenoxy-butyric acid	2,4-DB	30 ppm (1.22×10^{-4}M)	+	?	+
tris(2,4-dichlorophe-noxyethyl) phosphite	Falone	60 ppm (0.92×10^{-4}M)	+	?	+
bis(2,4-dichlorophe-noxyethyl) phosphite	none	90 ppm (1.96×10^{-4}M)	+	?	+
2,4-dinitrophenol	2,4-DNP	3 ppm (1.63×10^{-5}M)	+	++	+
phenol	none	none*	–	–	–

*No effect found up to 125 ppm or 1.33×10^{-3}M.

OBSERVATIONS

Cytological effects

All of the substances tested had two distinguishable effects on mitosis; 1. spindle inhibition resulting in chromosome configurations very similar to those produced by colchicine (Figure 1A), and 2. ultimate inhibition of the onset of mitosis. In addition, several of them, most notably 2,4–DNP, and 2,4–dichlorophenoxyacetic acid, 2,4–D, indicated interference with the transition of the chromosomes from late prophase configurations to prometaphase. The appearance of these late prophase chromosomes resembled a telophase chromosome in that they were fuzzy in outline (Figure 1B). The question of whether these effects are the result of a single primary action, or are the result of separable actions, has not yet been answered. This is an important question, for if in some organisms the colchicine type response is accentuated and the other responses are reduced to a minimum, a high degree of polyploidy might be expected to develop. In any event, whether separable or not, in this report, the reactions are considered separately.

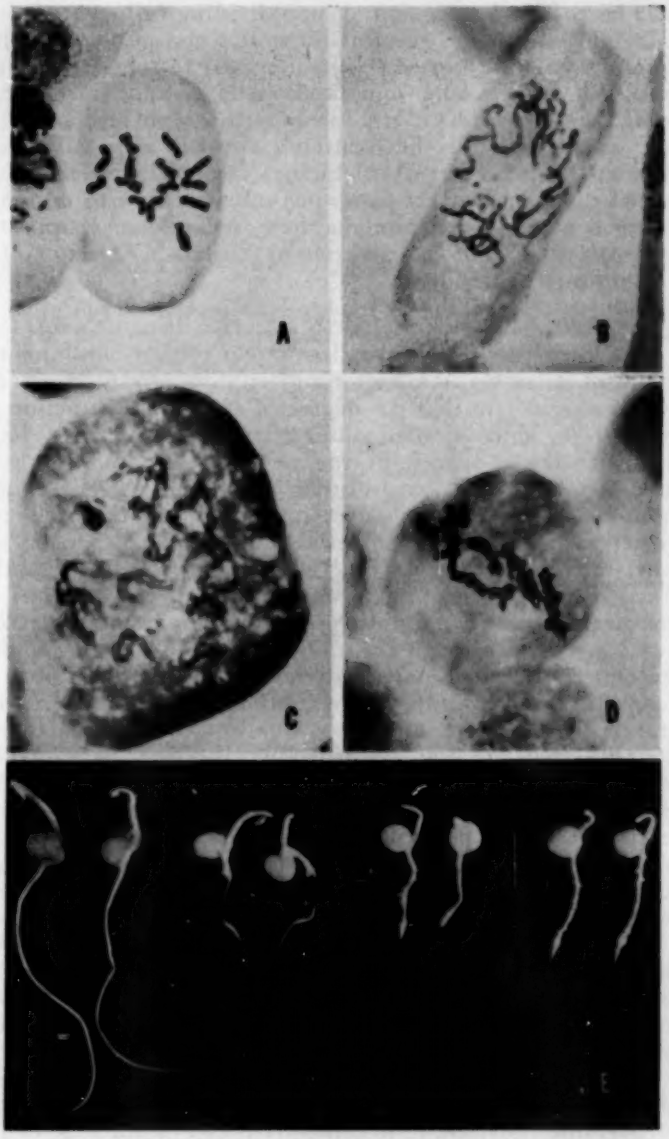

Figure 1. Diagnostic chromosome configuration and morphological abnormalities in pea root meristems produced by phenols.
A. "Scatter" produced by bis(2,4–dichlorophenoxyethyl) phosphite.
B. Reverting late prophase produced by 2,4–dinitrophenol.
C. Polytene prophase induced by 2,4–dichlorophenoxybutyric acid.
D. Polytene metaphase induced by 2,4–dichlorophenoxybutyric acid.
E. Morphological abnormalities produced by tri(2,4–dichlorophenoxyethyl) phosphite.

(a.) The colchicine reaction: When dividing cells are exposed to the alkaloid colchicine, certain diagnostic chromosome configurations result; namely, "scatters" which appear to represent failure of chromosomes to become organized on a metaphase plate, and "clumps" which represent stalling at prometaphase. According to Hadder and Wilson (9), the "scatters" represent a partial effect and the "clumps" a full effect of colchicine. The colchicine reaction was measured quantitatively by assigning values of zero to normal post prophase configurations (prometaphase, metaphase, anaphase, and telophase), one to "scatters" and two to "clumps". An index of effect was determined accordingly:

$$\text{Index} = \frac{\text{(number of scatters)} + 2\text{(number of clumps)}}{\Sigma\ \text{(normal post prophase)} + \text{(number of scatters)} + \text{(number of clumps)}}$$

The plot of index versus time for a given dose produced curves that were characteristic in that the degree of effect was a function of log dose-log time. Since similar configurations in the same order of occurrence were produced by the phenolic compounds, the same method of scoring was used in order to compare the effects of these compounds with colchicine effect curves. During the early part of the reaction, the phenolic curves resemble those produced by colchicine, but in no case was full effect observed. The inability to produce a full colchicine effect was due to either 1. toxicity which decreased the number of dividing cells, or 2. an apparent decrease in effect by a chemical with time. The latter was indicated by the increased appearance of normal division figures and was observed at low concentration levels that were relatively non-toxic. In most cases, the range of effective doses was too small to allow satisfactory study of dose effects. Some dose range studies, however, were made with 2,4–dichlorophenoxyethanol in several forms (Figure 2). The relationship between doses was found to be very similar to that of a range of colchicine doses until toxicity symptoms appeared.

While the production of similar chromosome configurations in similar order does not prove that the reaction is truly a colchicine type, it is at least suggestive. The fact that full effect (Index of 2) was never observed may be explained partially by the strong tendency to revert to normal. In addition, the interference at late prophase which is sometimes produced would block stages which normally could produce a colchicine type reaction. Presumably the appearance of significant amounts of polyploidy in recovered seedlings would provide further evidence. So far, only 2,4,6–trichlorophenoxyacetic acid, 2,4,6–TA, has consistently produced a reasonable amount of recoverable polyploidy. It probably is significant that this is the only compound which produced a fairly high colchicine index before toxicity made recovery impossible. Other workers (3, 17, 5) have reported recovery of polyploidy after treatment with 2,4,5–trichlorophenoxyacetic acid, phenyl mercurials, halogenated phenols, etc. Also, Kuang and Wilson (unpublished) recovered some polyploidy after treatment of *Allium* roots with 2,4–D, although the results were not consistent. Some polyploidy was observed in *Pisum* root meri-

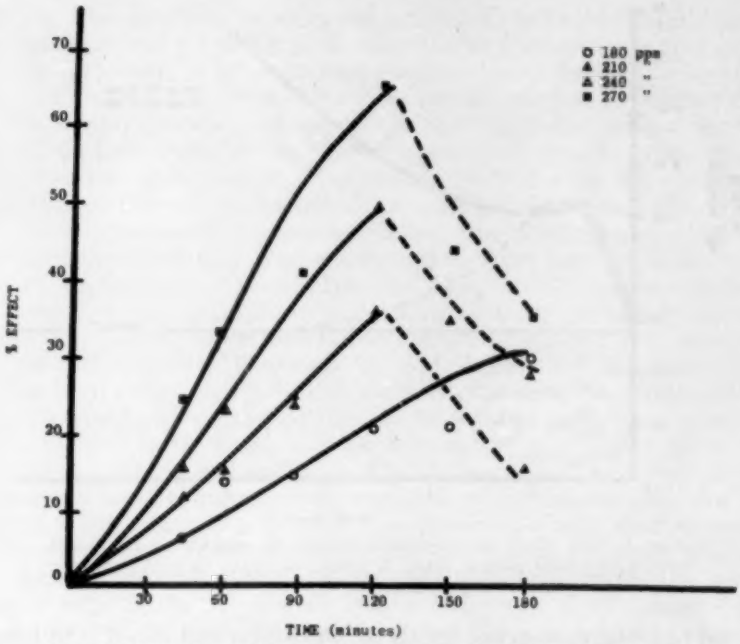

Figure 2. The effect of 2,4–dichlorophenoxyethanol on mitosis in pea roots over a three hour period. Effect is measured as percent of abnormalities in post prophases.

stem cells of recovered seedlings that had been treated with 2,4–dichlorophenoxybutyric acid, 2,4–DB. The polyploidy, however, obviously arose from stimulation of cortical cells, which were polytene, into division (Figures 1C, 1D).

(b.) The prophase poison reaction: A wide range of chemicals appear to inhibit transformation of dividing nuclei from late prophase into prometaphase. These chemicals have been referred to as prophase poisons (7). The major symptom of such an effect is the increase of late prophases relative to other stages, as compared to controls. Such chromosomes become telophase in morphology while still late prophase in spatial arrangement. All prophase poisons also inhibit the onset of mitosis. Of the phenolic compounds tested, 2,4–DNP and 2,4–D clearly appear to fall into this category as well (Figure 3). Others suggest this possible reaction. Our standard for this reaction was the antibiotic, actidione, the cytological effect of which has been studied intensively (2, 9). It was interesting to note that appropriate combinations of colchicine and actidione mimic, quite well, the general cytological effects of 2,4–DNP and 2,4–D. The possibility that these two cytological actions of the phenolic compounds were independently induced, therefore should be left open.

(c.) Chromosome fragmentation: Many phenolic compounds have been reported to cause chromosome breakage and therefore are sus-

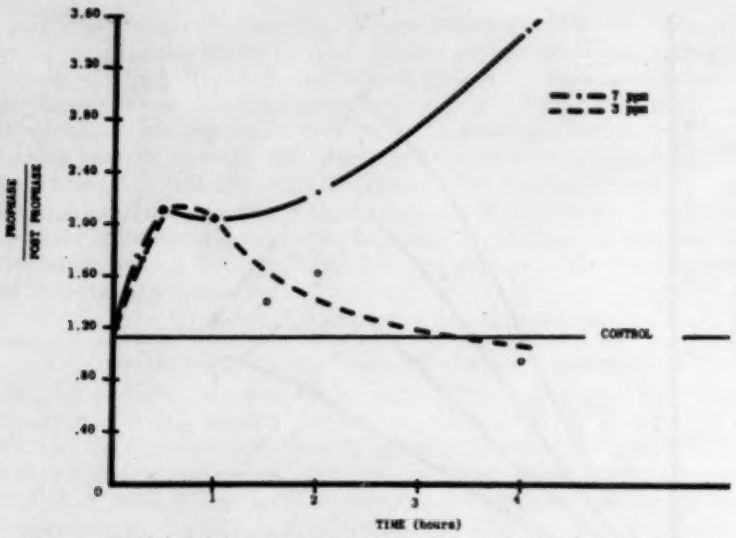

Figure 3. The effect of 2,4–dinitrophenol on mitosis in pea roots over a four hour period. Effect is measured as the ratio of prophase to post prophase configurations.

pected of being mutagenic agents (13). Loveless and Revel (15), however, failed to find evidence of breakage, and our work has shown little indication of chromosome fragmentation following treatment of roots with the phenolic herbicides.

(d.) Morphological effects: Certain morphological changes were characteristic of recovered seedlings. These included cessation of growth of the primary meristem, the occurrence of a tumor-like swelling, and stimulation of secondary root production (Figure 1E). Also, seedlings which were recovered long enough for adequate measurement were markedly stunted.

The cytological effect of the chemicals tested is summarized in Table 1. The lowest concentration level for cytological effect was the minimal limit below which quantitative measurements of effect were either not possible or unreliable. The concentrations listed were established experimentally by treating seedlings with amounts ranging from those which produced no effect to those which were almost immediately lethal. Whether or not the cytological effects described may be used as an index of herbicidal potential is still an open question. So far as suitable information is available, the evidence does suggest a general relationship.

DISCUSSION

From the cytological point of view, all of the phenoxy compounds screened produce somewhat similar effects. How these effects may be correlated with herbicidal value, is far from clear. However, it is reasonable to assume that they all have similar basic physiological

effects. The similarity between the actions of the herbicidal phenoxy compounds and 2,4–DNP is of considerable interest since this compound is known to affect certain enzyme systems in a fairly specific fashion. In the first place, 2,4–DNP is a powerful uncoupler of the oxidation-phosphorylation system in both plant and animal tissues (1, 14, 6). Low doses (10^{-6} to 10^{-4}M.) stimulate oxygen uptake at least temporarily, while higher doses (above 10^{-6}M.) produce a marked inhibition. Clowes (6) has shown a correlation between 2,4–DNP induced suppression of phosphorylation and inhibition of cell division in sea urchin eggs. These observations have been generally confirmed by the work of Hamburger and Zeuthen (10). The suggestion, of course, is that respiration and mitotic activity are closely associated. The nature of the association has been discussed by a number of authors including Bullough (4), and Wilson and Morrison (19). It has been shown that 2,4–DNP markedly inhibits the mitotic activity in excised pea roots when they are exposed to glucose stimulation (20). On the other hand, a large number of supposed respiratory inhibitors (KCN, malonic acid, KF, arsenates and arsenites) have produced no deviations in active mitosis which can be classified as either a colchicine or actidione type. Monoiodoacetic acid or iodoacetamide, both disrupt active mitosis, but not in a manner similar to phenolic induced disruption. No chemical known to disrupt some major step in the respiratory system has given a colchicine type reaction and the only evidence of direct relation between oxygen availability and the actidione reaction is the fact that under certain circumstances, an increase in late prophases, as compared to controls, has been observed in excised roots, when deprived of oxygen.

Since excess phosphate is known to disrupt mitosis (8) in a manner superficially similar to the phenolic induced deviation, and since 2,4–DNP leads to accumulation of phosphate it is possible that, at least, part of the cytological effect is explicable on this basis. Salt accumulation may also be a factor since this is closely associated with respiratory activity (11).

That molecular configuration is a factor in both the degree and site of action, is almost certain (18). Since the compounds studied appear to have similar effects, some common characteristic might be expected. Phenol itself does not appear to have an action such as that of the substituted phenols, thus the kind of substitution appears to be a major factor. A wide range of substitutions for the hydroxyl group appears to have little influence on the qualitative effect although they do have a quantitative effect. Leaper and Bishop (12) found that having two unsubstituted positions on the benzene ring opposite each other increases the effectiveness. From our work there is reason to believe that substitution (especially with chlorine) at the two position plays a major role in capacity to induce mitotic aberrations.

Seedlings treated with all compounds in these tests had a strong tendency to revert to normal mitotic behavior while still in treatment when the dose used was not quickly lethal. Experiments show that *Pisum* seedlings absorb a large portion of the compounds in a

short period of time, so that the concentration in the treatment chamber falls below the effective threshold. This may in part explain the "recovery" effect. In addition, the rapid uptake of the toxic substances by the seedlings may partially destroy the absorption mechanism of the roots so that further absorption of the compound cannot occur. The possibility of enzymatic breakdown of the compound in the treatment chamber by the roots cannot be entirely disregarded. Lundgardh (16) has similarly reported that the inhibition of salt absorption in the presence of cyanide or azide was removed when the tissue had been in contact with these substances for several hours. He attributes this to a possible adaptation of the enzyme system involved.

SUMMARY

The meristematic region of *Pisum* seedlings was treated with a number of substituted phenols and cytologically analyzed for mitotic abnormalities. All of the substances showed two distinguishable effects on mitosis: 1. a reaction quantitatively and qualitatively similar to that of colchicine, and 2. ultimate inhibition of the onset of cell division. In addition, some of the substances showed a third effect; that is, the increase of over-contracted late prophase configurations superficially resembling those produced by the prophase poison, actidione.

Although a reasonable amount of polyploidy was recovered in only one of the compounds tested, the colchicine index produced by all others showed that they were potential polyploidizing agents.

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An Environment System for Plant Studies with Controlled Temperature, Humidity, and Light[1]

RICHARD BEHRENS[2] and HOWARD L. MORTON[3]

NEED for reliable information concerning the effects of environment on the response of plants to herbicides motivated the construction of the controlled environment system described herein. A unit suitable for such studies should have these general specifications: 1. a useful range of control of light, temperature, and relative humidity; 2. no recirculation of air, to avoid overall contamination of the unit by volatile herbicides; 3. capability of maintaining several sets of conditions simultaneously; and 4. a design which may be modified easily. The system described was constructed with these points in mind.

A schematic diagram illustrates the major structural components of the environment system (Figure 1). Outside air enters the cooling

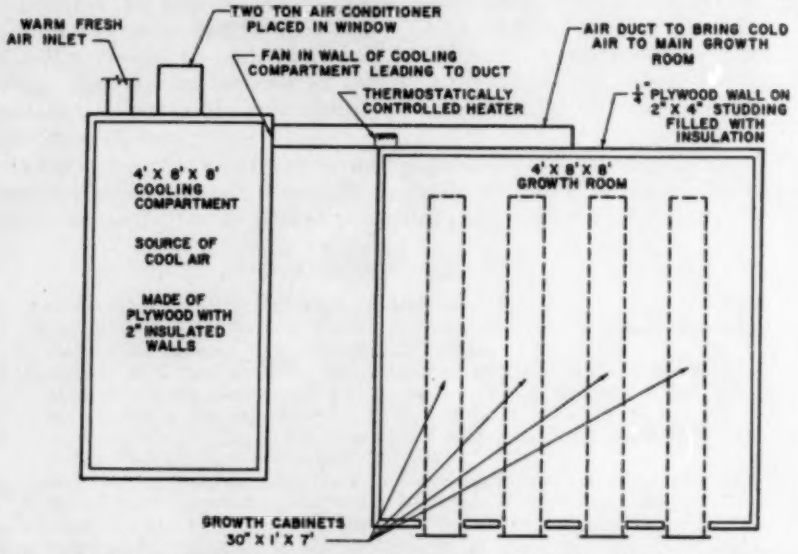
WARM FRESH AIR INLET
TWO TON AIR CONDITIONER PLACED IN WINDOW
FAN IN WALL OF COOLING COMPARTMENT LEADING TO DUCT
THERMOSTATICALLY CONTROLLED HEATER
AIR DUCT TO BRING COLD AIR TO MAIN GROWTH ROOM
¼" PLYWOOD WALL ON 2" X 4" STUDDING FILLED WITH INSULATION
4' X 6' X 6' COOLING COMPARTMENT
SOURCE OF COOL AIR
MADE OF PLYWOOD WITH 2" INSULATED WALLS
4' X 8' X 8' GROWTH ROOM
GROWTH CABINETS 30" X 1' X 7'

Figure 1. Schematic diagram (top view) of the controlled-environment system showing the arrangement of the air conditioner, cooling compartment, connecting air duct, growth room and growth cabinets.

compartment, which is maintained at a suitably low temperature by means of a refrigerator-type air conditioner. The cooling compartment serves as a continuous source of air at a selected tempera-

[1]Cooperative investigations between the Crops Research Division, A.R.S., U.S.D.A., and the Texas Agr. Exp. Sta., College Station.

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ture and relative humidity for the growth room. Four growth cabinets located within the growth room utilize the conditioned air. Control systems incorporated in the growth cabinets condition the air to the temperature and humidity levels desired within each growth cabinet. Then the air is passed over the plant material and exhausted from the system.

Cooling system.

The cooling compartment consists of a 250-cu. ft. plywood box insulated with glass wool. A 22,000-B.T.U., refrigerator-type air conditioner mounted in one end cools and thoroughly mixes incoming air with that already present. An essential feature of the cooling process is the removal of moisture from the air. Recirculation of air within the cooling compartment greatly increases the effectiveness of dehumidification. When the temperature of incoming air is 80° F. or higher, a minimum of 50° F. can be maintained in the cooling compartment. At temperatures below 50°, moisture freezes on the cooling coil, which eventually blocks the flow of air through the coil. When outside temperatures are below 80°, lower temperatures can be attained in the cooling compartment because the cooling system operates intermittently and ice does not accumulate on the cooling coil.

Connecting duct.

An insulated metal duct carries air from the cooling compartment to the growth room. An 8-inch, 3-speed fan and a heating unit are mounted in the duct. The fan facilitates the flow of air through the system. The heating unit, controlled by a thermostat mounted in the growth room, maintains the air temperature at the level desired.

Growth room.

The growth room is an insulated, 8-foot by 8-foot plywood box having a height of 4 feet (Figure 2). The top is covered with $^3/_{16}$-inch transparent plastic (Plexiglass). The front has openings for insertion of the growth cabinets. Conditioned air from the connecting duct enters the growth room through an opening at the rear. Two 10-inch fans circulate the air within to insure a uniform environment throughout the growth room.

The growth room serves three purposes: 1. It surrounds the growth cabinets with air of uniform temperature and humidity which insulates them from external fluctuations in temperature and humidity; 2. by means of the transparent top, it permits the use of an externally mounted illumination system which lessens considerably the amount of heat introduced into the air conditioned area, thus permitting the use of a small capacity, low cost air conditioner; and 3. it serves as a reservoir of conditioned air for the growth cabinets.

Growth cabinets.

Each of the four growth cabinets consists of a ¾-inch plywood base with a ⅛-inch transparent plastic superstructure (Figure 3). Their dimensions are 7 feet long, 1 foot wide, and 2½ feet high. The

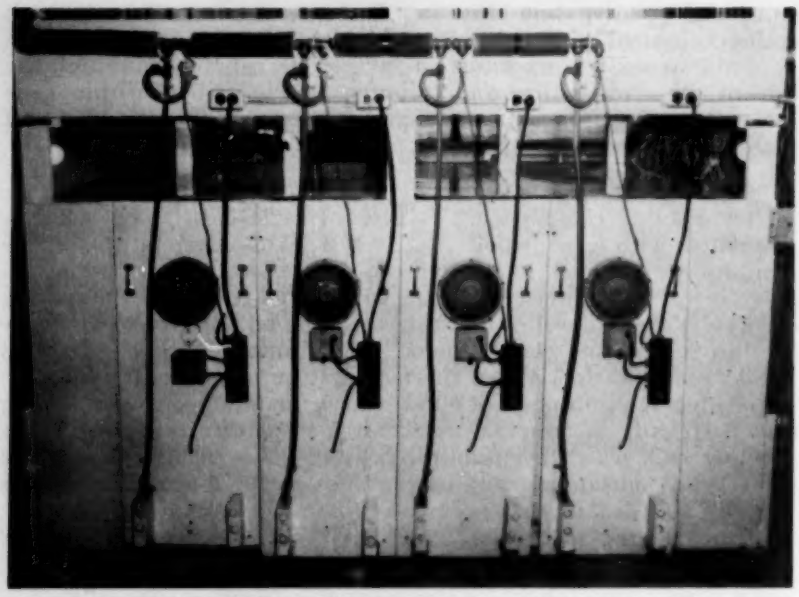

Figure 2. Front view of the growth room. The four front panels of the growth cabinets support the fans, temperature-control breakers, switches, and pilot lights. Mounted above the panels are the live steam and electrical power sources. At lower left is the drain pipe which carries the steam condensate from the growth cabinets to a floor drain.

top is removable and plants are handled through this opening. The growth cabinets are mounted on casters, which facilitates insertion in and removal from the growth room when servicing is necessary. Each cabinet is equipped with temperature and humidity control systems with the necessary heating and humidification being accomplished within an insulated aluminum pipe, 5 inches in diameter. The pipe is mounted under the cabinet proper and also serves as an air intake. Air enters the rear of the growth cabinet from the aluminum pipe. It passes over the plant material and the recording and control instruments and is then expelled by a 6-inch exhaust fan mounted in the front of the cabinet. A complete air change within each of the growth cabinets is accomplished in slightly less than 15 seconds.

Lighting system.[4]

The light source is composed of 52 cool white, Slimline fluorescent tubes, 8 feet in length, mounted on an 8-foot by 8-foot, ¾-inch plywood panel. This panel is suspended over the transparent top of the growth room. The T–8 Slimline tubes are energized by T–12 lag lead ballasts mounted on a wall adjacent to the system. Six 150-watt,

[4]Lighting-system components suggested by M. W. Parker, Crops Research Division, A.R.S., U.S.D.A., Beltsville, Maryland.

Figure 3. Side view of a growth cabinet removed from the growth room. The 5-inch aluminum pipe, in which the heating elements are mounted, is shown beneath the cabinet proper. Steam is introduced into the pipe by means of the copper tubing leading from the front panel.

incandescent bulbs are mounted along the edges of the chamber to supplement the red portion of the light spectrum to assure light of a quality nearer to that of sunlight. Initially, the light intensity was 2200 foot-candles at plant level. After 1 year of operating time, the light intensity from the same tubes had fallen to 750 foot-candles. The necessity of systematic tube replacement is evident if the higher light intensity is desired. Differences in light intensity between the growth cabinets were less than 10 percent at both light intensities.

Temperature-control system.

Cone-type heaters are used throughout the system because of their low cost, ease of mounting, and the variety of sizes (15 to 660 watts) that are available. The large heating unit mounted in the connecting duct was built of a number of cone heaters mounted on a fireproof base. Some of the elements in this heating unit operate continuously, and the remaining ones are thermostatically controlled. This arrangement reduces the temperature fluctuations due to intermittent operation.

Inexpensive wafer-type thermostats designed for use in brooder stoves are used to control temperature.

Humidity-control system.

Relative humidity has proved to be the most difficult factor to control. Dehumidification is accomplished in the cooling compartment. The lowest humidity level is determined by the temperature of the cooling compartment and the temperature to which the air is heated in the growth cabinets. Live steam is utilized as a moisture

source in humidification. Steam is introduced continuously through the aluminum intake pipe at a rate just below that required for a given level of relative humidity. A final small part of the steam flow is controlled by a hygrostat[5] which operates a solenoid valve in the steam line. By the combination of continuous and intermittent steam flow fluctuations in relative humidity are minimized. Components of the apparatus used to control relative humidity are shown in Figures 2 and 3.

General operation.

In present operations, four growth cabinets are being used. However, a smaller number of larger cabinets or a larger number of smaller cabinets could be used with slight modifications of the openings into the growth room. Temperatures ranging from 65 to 100° F. can be maintained simultaneously provided polyethylene film dividers are used to partition the growth room. A relative humidity range of 20 to 100 percent is possible when the operating temperature of a growth cabinet approximates 85° F. The lighting system is operated manually; however, time switches could be installed. Variations in light intensity between individual growth cabinets may be effected by means of translucent or opaque covers. It is necessary to remove the tops of the growth cabinets to service the plants. The tops are secured by means of bolts and wing-nuts, which permit rapid removal and replacement.

For short-term experiments plants are grown in the greenhouse to the desired stage of development and then placed in the growth cabinets. For long-term experiments plants are placed in the growth cabinets immediately after germination and grown to the desired age or stage of development. Plants grown for two months in the growth cabinets produced normal growth.

Cost of materials for system.[6]

Total cost of the system, excluding labor, was $2200. The costs of the materials, broken down according to the functions for which they were purchased, are as follows: Structural components of the system cost $600, of which $270 was needed to purchase the plastic used to cover the top of the growth room and construct the superstructures of the growth cabinets. The air conditioner cost $350. Lighting equipment cost $500. Fans for circulation of air and components of the heating system each cost $100. Humidification equipment cost $550.

SUMMARY

An environment system is described which provides control of light, temperature, and relative humidity. Major features of the system include non-recirculation of air and capability of maintaining four sets of conditions simultaneously.

[5]The hygrostat consists of a controller with remotely mounted electric sensing element.

[6]Mimeographed list of the source and cost of components will be supplied by authors on request.

Several Triazines as Selective Post-emergence Herbicides in Cotton

JOHN T. HOLSTUN, JR. and S. W. BINGHAM[1]

THE efficiency of cotton production has been materially increased since 1949 through the use of several pre- and post-emergence herbicides (2, 4, 5, 6, 10, 14, 17, 18, 19). In the high-rainfall areas, combinations of a pre-emergence herbicide such as isopropyl *N*–(3–chlorophenyl)carbamate (CIPC) or 3–(3,4–dichlorophenyl)–1,1–dimethylurea (diuron) with one of several post-emergence oils have given more dependable control than the use of single herbicides. In the irrigated areas, early-season weeds have been less of a problem and more attention has been given to herbicides for the control of late-appearing grasses and vines. The substituted ureas, 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron) and diuron, have been the most successful herbicides for this use.

The initial effectiveness of currently recommended pre-emergence herbicides is greatly influenced by surface moisture. They do not normally provide more than 6 weeks of control, do not always control all susceptible weeds, and their effectiveness is reduced or lost in the event the crop has to be replanted. The herbicidal oils used in the high-rainfall areas are difficult to use, should not be used on older stages of cotton, and have no residual effect. Post-emergence applications of diuron and monuron depend on adequate surface moisture for effectiveness and have relatively little effect on emerged weeds. Thus, despite considerable progress there still remains a real need across the entire Cotton Belt for an effective, economical, and easy-to-use post-emergence herbicide. Such a herbicide should kill seedling and established weeds and prevent the development of weeds from seed in the soil. Numerous workers have reported promising results with several herbicides, but with the exception of certain lay-by treatments, none of the evaluated treatments have been put into practical use. Expense of the treatments, lack of sufficient selectivity, failure of the treatments to control both ungerminated and established weeds, and dependence of the treatments on soil moisture have prevented general acceptance of the herbicides. The study reported in this paper was conducted in an attempt to develop weed-control methods that would avoid or minimize some of the problems listed. It has been primarily a field study with a limited amount of supporting greenhouse work.

MATERIALS AND METHODS

Preliminary work at Stoneville, Mississippi, indicated that 2–chloro–4,6–bis(diethylamino)–*s*–triazine (CDT) possessed some of the qualities desired in a post-emergence herbicide for cotton and that

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the carrier used for the herbicide was extremely important. Other workers (1, 3, 7, 11, 12, 15, 20, 21, 22) have described the activity of CDT and other triazines as both pre- and post-emergence herbicides in various crops. The post-emergence studies reported here were conducted with CDT and six related triazines,
2–chloro–4–diethylamino–6–isopropylamino–*s*–triazine (ipazine),
2–methoxy–4,6–bis(ethylamino)–*s*–triazine (methoxy simazine),
2–chloro–4–ethylamino–6–diethylamino–*s*–triazine (trietazine),
2–chloro–4,6–bis(ethylamino)–*s*–triazine (simazin),
2–chloro–4,6–bis(isopropylamino)–*s*–triazine (propazine), and
2–chloro–4–*n*–propylamino–6–isopropylamino–*s*–triazine (G–30451). Phytobland oils[2] or water-surfactant[3] mixtures were used as carriers. Three field experiments were conducted. In all of these experiments cotton (*Gossypium hirsutum* L. variety DBES 7343) was planted by hill-dropping with a tractor-mounted planter. Weeds present included pigweed (*Amaranthus* spp.), brachiaria (*Brachiaria* spp.), morning-glory (*Ipomoea purpurea* (L.) Roth), crabgrass (*Digitaria sanguinalis* (L.) Scop.), and nutgrass (*Cyperus rotundus* L.). The soil type was Bosket very fine sandy loam. All chemicals were applied in a broadcast volume of 40 gal/A on a 12-inch band centered on the drill. Other methods varied from one experiment to another.

First experiment.

Seven triazines, CDT, ipazine, methoxy simazine, trietazine, simazin, propazine, and G–30451, were compared in 1957 in randomized complete blocks with two replicates. Plots consisted of two 40-inch rows 74 feet long.

Water plus 0.5 percent (W/V) surfactant was used as the carrier for all herbicides. Each chemical was applied three times at a predetermined minimum rate (Table 1) to cotton when it was at the stages of 3, 6, and 12 inches tall, and at two and four times the minimum rate to 12-inch cotton. The directed method of spray application described by White (23) was used. Where the initial treatment was delayed until the cotton was 12 inches tall, initial control of weeds was maintained by use of a recommended herbicidal oil until the test chemical was applied. The middles were cultivated with a minimum amount of soil being moved onto the treated area. The results were evaluated by crop-reaction ratings, hoe-labor requirements, and late-season weed counts.

Second experiment.

CDT was evaluated at four rates in two carriers in cotton treated and not treated pre-emergence. One planting was made in 1957 and one in 1958. Because of heavy rains, the 1958 planting was replanted, and therefore each pre-emergence plot had two applications of the pre-emergence herbicide. A split-plot design in randomized complete blocks replicated four times was used. Sub plots consisted of two adjacent 40-inch rows 119 feet long in 1957 and two rows 80 feet

[2]Either white mineral oil or Bayol D.
[3]A polyoxyethylene thioether.

Table 1. Crop-reaction ratings, hoe-labor requirements, and late-season weed counts in cotton planted May 8 and treated with post-emergence herbicides applied in water on May 21, May 29, and/or June 17, Stoneville, Mississippi, 1957. (Average 2 replications.)

Treatment		Height cotton at application[a] inches	Crop-reaction rating[b]	Hoe-labor requirement hr/A	Annual weeds August 2 no./ft²
Herbicide	Rate/application lb/A				
Methoxy simazine	3.0	12	0.0	—	1.11
	6.0	12	0.0	—	.63
	1.5	3,6,12	0.0	14	.55
Ipazine	3.0	12	0.0	—	.64
	6.0	12	0.0	—	.35
	1.5	3,6,12	0.0	20	1.32
CDT	6.0	12	0.0	—	.68
	12.0	12	0.0	—	.63
	3.0	3,6,12	0.0	41	1.08
Simazin	3.0	12	0.0	—	.02
	6.0	12	0.0	—	.24
	1.5	3,6,12	3.5	16	.74
Propazine	6.0	12	0.0	—	.42
	12.0	12	0.0	—	.80
	3.0	3,6,12	6.0	19	.75
G-30451	6.0	12	0.0	—	.40
	12.0	12	0.0	—	.70
	3.0	3,6,12	6.5	10	1.38
Trietazine	3.0	12	0.0	—	1.03
	6.0	12	0.0	—	.36
	1.5	3,6,12	0.0	36	.83
None (hoed check)	—	—	0.0	50	1.30

[a]The plots which did not receive listed treatment until cotton was 12 inches high received two applications of herbicidal oil to kill weeds prior to listed treatment. Hoe-labor requirements were omitted for these treatments since they were confounded with the herbicidal oil treatments.
[b]1,2,3 = slight injury; 4,5,6 = moderate; 7,8,9 = severe injury.

long in 1958. Diuron pre-emergence at 1 lb/A versus no pre-emergence constituted sub-plot treatments. Main plots (post-emergence treatments) consisted of the four adjacent rows used for the two sub-plot treatments. Water plus surfactant (2.0 percent (W/V) in 1957 and 0.5 percent (W/V) in 1958) and phytobland oils were used as the carriers.

When they were needed for weed control on the weediest sub plot, the post-emergence treatments were applied to main plots. In 1957 the phytobland oils caused limberness of cotton stems if applied after appearance of bark cracks on the cotton stems. Because of such limberness water-surfactant was used as the carrier in all plots for the last application in 1958. The post-emergence treatments were applied four times except that in 1957 the two higher rates were applied only twice. In applying post-emergence treatments the directed-spray method described by Bingham et al. (6) for herbicidal oils was used for the first two applications in 1957 and the first application in 1958. The directed method described by White (23) was used for all other applications. The cotton was about 2 to 3 inches high at the first application in the 1957 planting. In the 1958

planting, much of the cotton was about 1.5 inches tall at the first application.

In 1957, all plots treated post-emergence were cultivated using shields which moved a minimum amount of soil onto the drill area. The check plot was cultivated in the conventional way whereby soil was intentionally moved onto the drill area to smother small weeds. The same cultivation procedure was used in 1958 except that all plots received one conventional cultivation 3 days prior to the last post-emergence application. All plots were hoed as needed within the limitations imposed by weather. The results were evaluated by use of hoe-labor requirements and yields supplemented by weed and crop-reaction notes, stand counts, and weed counts.

Third experiment.

Ipazine and methoxy simazine were evaluated in 1958 at three rates in two carriers in plots of cotton treated and not treated pre-emergence with diuron at 1 lb/A. As with the 1958 planting of the second experiment all plots were replanted and retreated with the pre-emergence herbicide. The carriers used, number of replicates, experimental design, evaluation of results, and plot size were identical with the 1958 planting of the second experiment. The herbicidal-oil method of application was used only for the first application and White's method was used for the remainder. Post-emergence treatments on the main plots were applied when weed control was needed on the no-pre-emergence sub plots. The highest rate of methoxy simazine in oil was applied only once because of the severe injury it caused. Three applications of all other post-emergence treatments were made. The cultivation procedure was the same as used in the 1957 planting of the second experiment in which shields were used except for the check plots.

RESULTS

The first evaluation of CDT at Stoneville for post-emergence use in cotton was in 1955. The other six triazines included did not become available until later. For this reason more work was conducted with CDT and it was used as a standard for comparison of the other six in the first of the three experiments now being reported.

The results of the first experiment are shown in Table 1. None of these triazines produced detectable injury to the cotton if application was delayed until the cotton was 12 inches high. On young cotton simazin, propazine, and G–30451 caused considerable chlorosis, and the last two caused stunting which persisted for several weeks. Of the herbicides that were more selective on young cotton, methoxy simazine and ipazine were much more effective in controlling weeds. These results served as the primary basis for selection of treatments for one of the 1958 experiments. The most promising material for use as a lay-by treatment was simazin. In general, late-season weed emergence was inhibited more per pound of chemical by a single application at the 12-inch stage than by split-applications termi-

nating at the 12-inch stage. Loss by leaching and volatilization may have accounted for this difference. Late-season weed infestations were so light in the later experiments that the data collected were not considered reliable, and this phase of the evaluation will not be discussed for the second and third experiments.

Whereas the first experiment was designed primarily to compare relative selectivity of several compounds, the second test was conducted in an effort to find a way to increase the effectiveness of CDT and to determine crop tolerance limits of this herbicide. The data presented in Figure 1 are averages of the 1957 and 1958 results.

Phytobland oil was superior to water-surfactant as a carrier of this triazine in relation to weed control. One treatment, not included in Figure 1, was a 40 gal/A rate of the phytobland oil without CDT.

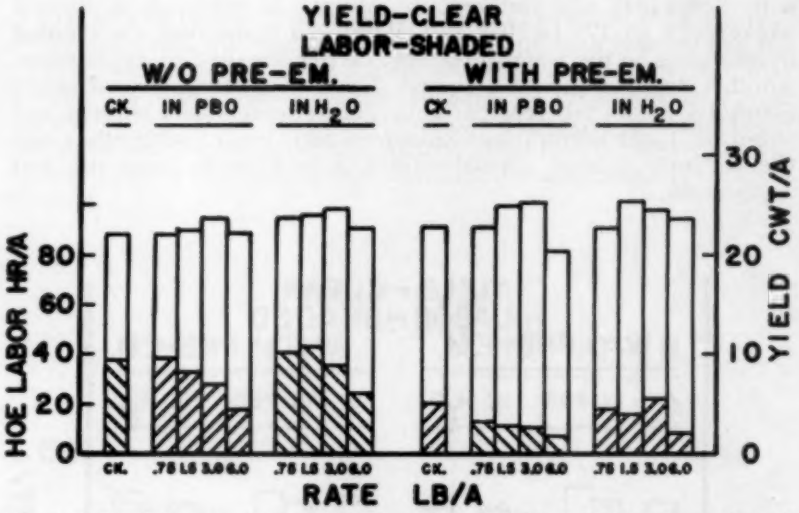

Figure 1. Hoe labor required to control weeds and yield of seed cotton as affected by post-emergence applications of CDT at four rates in phytobland oil and in water to plots of cotton treated and not treated with a pre-emergence herbicide. (Average 2 years, 4 replications, Stoneville, Mississippi, 1957–58.)

Weed control by the oil alone, as measured by hoe-labor requirements, was almost equal to the low rate of the herbicide in oil. Control of weeds by CDT in oil or in water was not spectacular in that the effect was largely to arrest development of the weeds rather than to kill them. At high rates, treated weeds slowly became chlorotic and many died. At low rates weeds tended to recover between treatments. Control of broadleaf weeds tended to be a little better than control of grasses. Significant control of nutgrass was obtained with most rates applied in oil, but this weed was not present in great numbers. Rate effects were apparent where oil was used as a carrier, but where water-surfactant was used the major rate difference was in the high rate versus all other rates. In comparison with

the appropriate check the proportion of weed control due to post-emergence treatment was higher on the pre-emergence plots than on the no-pre-emergence plots. It is doubtful whether CDT alone can safely provide the positive control needed for general use. It might have value, however, as a supplement to a good pre-emergence herbicide or in areas where early-season growth of weeds is less vigorous.

Prior to harvest in 1957, the only indication of effect on the cotton plants was due to the action of the phytobland oil on the stem. Cotton treated four times with phytobland oil, either with or without CDT became temporarily limber. A subsequent greenhouse test indicated that susceptibility to the oil was greatest when plants were 55 to 70 days old. The period of greatest susceptibility both in the field and in the greenhouse appeared to be similar to that associated with herbicidal oils and certain solvents as reported by several workers (13, 16, 17). In 1958, the oil-induced limberness was avoided by changing to the water-surfactant carrier for the last application. Another type of injury occurred, however. Cotton treated when about 1.5 inches tall reacted by becoming temporarily stunted and chlorotic. Later applications caused no additional visible effect and the cotton appeared normal within 3 to 4 weeks after the first application.

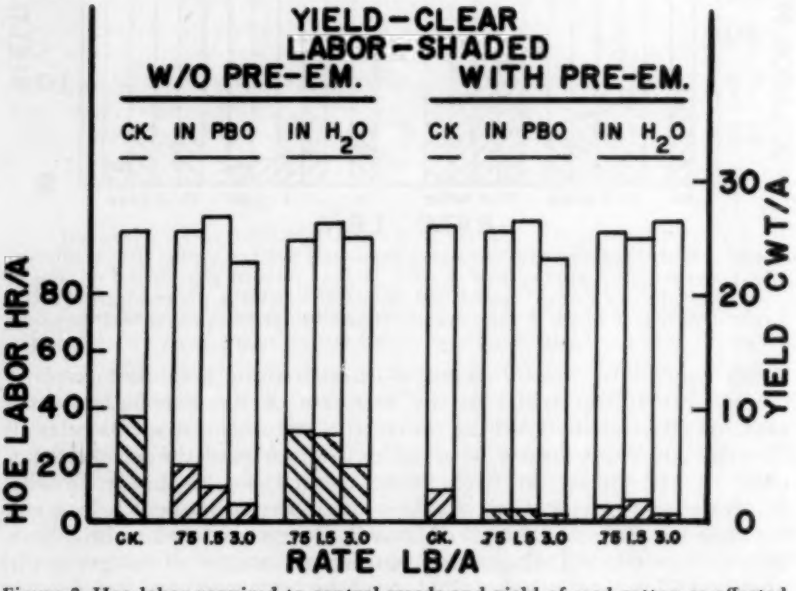

Figure 2. Hoe labor required to control weeds and yield of seed cotton as affected by post-emergence applications of ipazine applied at 3 rates in phytobland oil and in water to plots of cotton treated and not treated with a pre-emergence herbicide. (Average 4 replications, Stoneville, Mississippi, 1958.)

Statistical analyses of the 1957–58 yield averages indicated significant differences between post-emergence treatments only for plots treated pre-emergence. The lowest yielding plots were those that received pre-emergence treatment plus the highest rate of CDT in oil. The LSD at the 5 percent level of probability did not differentiate these plots from the appropriate check plots, but did separate them from several of the higher yielding CDT-treated plots. These results indicated that pre-emergence treatment, high rates of certain triazines, and oil carriers can combine to exert a depressing effect on yield.

The third experiment had the dual purpose of determining how to get the best results from a particular herbicide and whether ipazine or methoxy simazine was better for post-emergence use in cotton. The data are presented in Figures 2 and 3.

Ipazine and methoxy simazine were almost equal in weed control. Possibly ipazine was slightly superior with oil as a carrier, but the reverse was true with water-surfactant as a carrier. The fact that ipazine was formulated as a liquid concentrate which formed a good suspension in the oil, while the methoxy derivative formed only a fair suspension in oil may be related to these trends. As with CDT, oil was superior to water-surfactant as a carrier with respect to control of weeds.

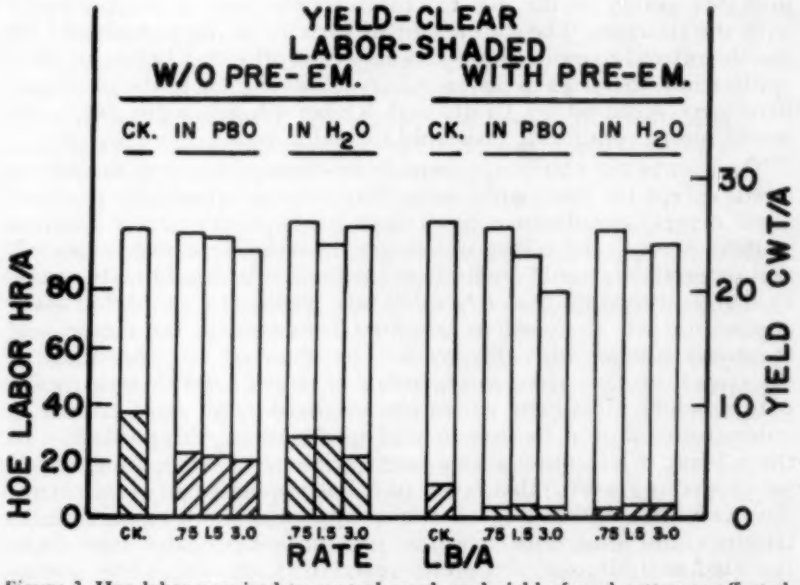

Figure 3. Hoe labor required to control weeds and yield of seed cotton as affected by post-emergence applications of methoxy simazine applied at 3 rates in phytobland oil and in water to plots of cotton treated and not treated with a pre-emergence herbicide. (Average 4 replications, Stoneville, Mississippi, 1958.)

Again as with CDT, the combination of high rates of methoxy simazine or ipazine in oil on plots treated pre-emergence caused reductions in yield. Statistical analyses indicated significant reductions only for the highest rate of each herbicide applied in oil on the plots receiving pre-emergence treatment. The corresponding treatments on the plots which received no pre-emergence treatment resulted in lower average yields, but these reductions were not significant at the 5 percent level of probability.

DISCUSSION

The herbicidal activity of the triazines included in these experiments is believed to be largely the result of absorption of the chemicals through the foliage of the treated plants. There appeared to have been some absorption of the herbicides from the soil and possibly some contact action. If these suppositions are correct, considerable action on emerged weeds without dependence on soil moisture should be expected. The advantage of the oil carrier over water-surfactant is believed to be the result of three factors. First, better coverage of the weeds was obtained with the oil. Second, the phytobland oil apparently is absorbed by plants and tends to move into the growing points, as indicated by supporting greenhouse studies. Comparative solubility studies of the triazines in the oil and in water are needed to provide more data on this point. The third factor is that the oil had a marked inhibitory effect on plant growth, which probably added to the general inhibitory action of combinations with the triazines. The nature of this toxicity of the phytobland oil may be related to oxidation reactions in the oil either before or after application. Increases in phytotoxicity of oils similar to the ones used here were reported by Crafts and Reiber (9) when the oils were stored under conditions favorable for oxidation.

Toxicity to the cotton appeared to be closely related to toxicity to weeds except for three differences. First, cotton apparently possesses some degree of tolerance to at least some of the seven triazines studied. Second, the cotton was larger than the weeds when treated, and theoretically equal amounts of the herbicide should be less toxic to a large individual than to a small one. Third, the method of spray application was designed to minimize contact with the cotton and maximize contact with the weeds. The observed fact that most of the crop injury occurred as the result of treating very young cotton plants, while practically no injury occurred from applications to older cotton should be investigated to determine the possibility of there being a triazine-sensitive enzymatic system in seedling cotton (or in seedling weeds) that is not or is less important in older plants. The fact that diuron-treated cotton appeared more susceptible to triazines and that both triazines and urea herbicides have been reported as inhibitors of the Hill reaction (8, 21) should be investigated in relation to the possibility of synergistic action between the two herbicides.

Volatility and residual soil toxicity hazards of the triazines should

be evaluated prior to attempts at practical use under farm conditions. Limited supporting tests indicated that these hazards do exist, but the test work was not extensive enough to describe the possible hazards quantitatively.

It is unlikely that any of the exact treatments in these studies will prove practical, but the data do indicate that modifications of the tested treatments should receive further research attention. Certainly the use of ipazine alone and in combination with a pre-emergence herbicide should be studied further. Application of this herbicide should be delayed until the cotton attains a height of at least 3 inches. Where used in conjunction with the pre-emergence herbicide, application could, and probably should be delayed, until the cotton is even larger. The choice of a phytobland oil as a carrier probably should be limited to the first one or two applications and then used only if necessary because of heavy weed growth. Rates for application in oil probably should not exceed 1 lb/A, while in water-surfactant mixtures rates up to 2 lb/A may be safe. Regardless of which of the two treatments were being studied, the use of "dirting" cultivation as a supplement to the chemical treatment should be considered. While some direction of the spray is needed, relatively simple application equipment can be successfully used to apply this triazine herbicide. The vertical direction of the spray alleviates, to some extent, the need for maintaining the smooth, flat, drill area required in the use of laterally directed herbicidal oils.

SUMMARY

The activity and selectivity of
2–chloro–4,6–bis(diethylamino)–*s*–triazine (CDT),
2–chloro–4–diethylamino–6–isopropylamino–*s*–triazine (ipazine),
2–methoxy–4,6–bis(ethylamino)–*s*–triazine (methoxy simazine),
2–chloro–4–ethylamino–6–diethylamino–*s*–triazine (trietazine),
2–chloro–4,6–bis(ethylamino)–*s*–triazine (simazin),
2–chloro–4,6–bis(isopropylamino)–*s*–triazine (propazine), and
2–chloro–4–*n*–propylamino–6–isopropylamino–*s*–triazine (G–30451)
were studied as directed post-emergence sprays for weed control in cotton in one or more field and greenhouse experiments at Stoneville, Mississippi, during 1957–58.

Ipazine was the most selective on young cotton, and its effective rate was approximately 2 lb/A. CDT and trietazine were intermediate in selectivity and were the least active of the seven herbicides. The others lacked practical selectivity in young cotton, but possessed promise for use in older cotton. Of the seven compounds evaluated, simazin possessed the highest residual activity and the greatest duration of weed control.

Phytobland oils were superior to water-surfactant mixtures as carriers for the herbicides in relation to weed control, but tended to increase the detrimental effects on the cotton. Significant reductions in yields of cotton were obtained from applications of high rates of CDT, ipazine, and methoxy simazine in phytobland oil on cotton

that had been treated pre-emergence with 3–(3,4–dichlorophenyl)–1,1–dimethylurea (diuron). Reducing the rate, changing the carrier to water-surfactant, or omitting pre-emergence treatment reduced or eliminated this adverse reaction.

ACKNOWLEDGMENTS

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Factors Affecting the Activity of 4–Chloro–2–butynyl *N*–(3–chlorophenyl)carbamate as a Selective Herbicide[1]

OTTO L. HOFFMANN, JOE W. PULLEN, JEAN R. EPPERLY and T. R. HOPKINS

4–Chloro–2–butynyl *N*–(3–chlorophenyl)carbamate (S–847) has been reported to show promise for selective control of wild oats in wheat, barley, flax, sugar beets, and peas (1). This paper presents data on the influence of several treatment conditions on wild oat control.

MATERIALS AND METHODS

Plants were grown in clay pots, seed flats or ground beds in the greenhouse. In the field, cultivated oats were sown in rows and S–847 was applied crosswise. In most of the greenhouse work an experimental unit consisted of wild oats and Selkirk wheat planted in the same 4" clay pot.

In the greenhouse a sprayer with a moving spray cart was used. The speed of the cart, the spray pressure, the nozzle size and the concentration of the solution could be varied to give the desired rate of application. Field plots were sprayed with a small plot sprayer mounted on bicycle wheels. Varied gallonage was obtained by walking at different rates (measured with a tachometer). Rates were obtained by varying the concentration of the spray mixture.

In most of the work reported here a formulated material containing one pound of active ingredient in a Velsicol AR–50G carrier with Atlox 2081 emulsifying agent was used. Velsicol AR–50G is a petroleum fraction containing mainly methylated naphthalenes. Appropriate dilutions were made in water.

RESULTS

Original screening. 4–Chloro–2–butynyl N–(3–chlorophenyl)carbamate was found to severely inhibit the growth of *Avena sativa* in a herbicide screen where wheat, flax, sugar beets, tomato, peas, millet and alfalfa were only temporarily inhibited. This test was run at a 10 pound per acre rate in 250 gallons of water per acre. The formulation contained Emulphor EL as a suspending agent and 1% emulsified kerosene as a penetrating agent. Since *Avena sativa* is closely related to the wild oat, *Avena fatua,* a need for further trials on the weed species was indicated.

Time of spraying. A preliminary trial where wild oats was sprayed at weekly intervals indicated that wild oats was only susceptible to S–847 during a relatively short time interval (1). Spraying at 4 days and 25 days after emergence was not so effective as at 11 and 18 days after emergence. At the susceptible spray times the wild oats was in

[1]Contribution from the Research Department, Spencer Chemical Company, Kansas City, Missouri.

the 1½ leaf (second leaf half as long as the first leaf) to the 2½ leaf (third leaf half as long as the second leaf) stages. Experiments over a wider range of growth conditions indicate that a simple designation of leaf growth is not an absolute criterion for estimating the optimum time to spray wild oats. Results from an experiment that illustrate the observed variations are illustrated in Figure 1. Control

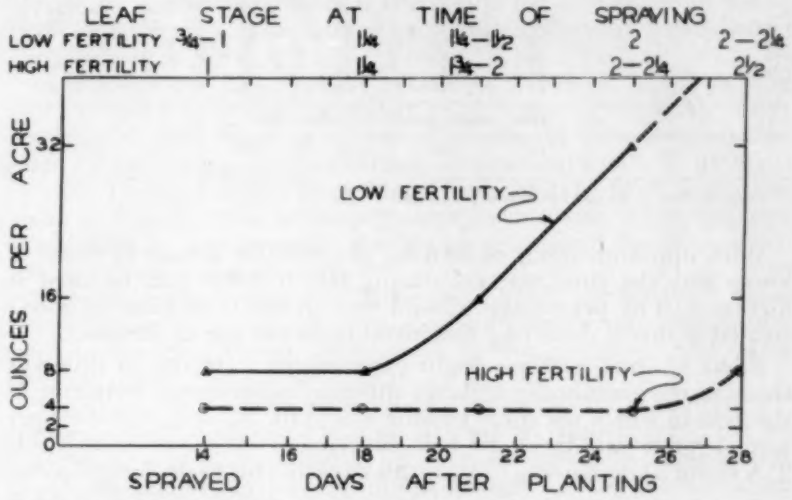

Figure 1. Effect of fertility level on response of wild oats to 4–chloro–2–butynyl *N*–(3–chlorophenyl)carbamate applied at different plant ages. Points on the curves indicate the minimum quantity of chemical required to inhibit wild oat growth for one month after spraying.

of wild oats is here arbitrarily defined as no significant growth for a period of one month after spraying. In most of the tests "no significant growth" was defined as less than 2½ cm. increase in height of the wild oat plants. However, when measuring the plants, the occasional plants that showed no effect were disregarded. With a heavy fertilizer application wild oats was susceptible to the 25th day after planting and to the 2¼ leaf stage. With a very low fertility level the wild oats was susceptible until the 18th day after planting when it was in the 1¼ leaf stage. In some field plots sprayed 16 days after planting, excellent selective control of cultivated oats was obtained at ¼ pound per acre of S–847 when the oats was in the 2½ leaf stage. In tests run so far, results with S–847 have been unsatisfactory when spraying was done after the 2½ leaf stage.

Fertilizer effect. Field observations indicated that best control was obtained in areas where the growth of the plants was rapid. The condition of the rapidly growing plants suggested that the increased growth was due to a higher fertility level in these localized areas. A greenhouse experiment was carried out to measure the fertility effect. Data on this experiment are contained in Table 1. The data in Figure 1 also bear on the fertility effect on S–847 activity.

Table 1. Wild oats as percent of green weight of Selkirk wheat and wild oats in 2 pots at various rates of S–847 and fertilizer.

Pounds S-847 per acre	Percent wild oats in total plant weight following					
	Milligrams 23–21–17 fertilizer per 4" pot[a]					
	0	100	200	800	1600	3200
0	38	31	41	38	38	36
1/16	31	33	39	37	22	24
1/8	25	18	21	12	12	1
1/4	20	25	15	1	0	1
1/2	25	27	14	1	0	0
1	27	33	20	6	1	0
	Total weight, grams, in 2 control pots					
	13	26	27	55	58	77

[a]Base soil low in phosphorus, low in potassium.

With optimum levels of fertility the effective dosage of S–847 is lower and the time interval during which S–847 can be used is increased. The percentage of wild oats in the total yield of S–847 treated plants is decreased considerably by the use of fertilizer.

Effect of spray volume. Eight experiments were run at different times in the greenhouse and two different experiments were run in the field in which the spray volume was 5, 10, 20, and 40 gallons per acre. Typical data from one field experiment are recorded in Table 2. A factorial design was used in this experiment. Eight formulations

Table 2. Effect of spray volume and rates of S–847 on the height of oats.

Rate S-847 lb/A	Height of oats, cm, following				
	Spray volume gallons per acre				
	5	10	20	40	mean
0					78.3
1/4	19.9	22.1	26.2	28.4	23.7
1/2	15.6	17.5	16.7	21.6	17.8
1	13.9	9.2	13.9	13.9	12.7
2	1.6	9.9	5.2	13.1	7.4
Mean	12.8	14.7	15.5	18.7	

L.S.D. of means of rate or spray volume 1.24 cm at the 5% level or 1.43 cm at the 1% level Rate x spray volume interaction 1.94 cm at the 5% level.

were used at four rates and four spray volumes. Since no difference was detected in the performance of the formulations only the gallonage and rate data are reported here. These data indicate that between 40 and 5 gallons per acre effectiveness of S–847 is inversely related to spray volume.

The straight line relationship did not hold for all rates as is indicated by an interaction between spray volume and rates that was significant at the 5% level. This interaction appears to be related to the ratio of the emulsifiable concentrate to the water. In this experiment the peak performance occurred where one part of emulsifiable concentrate was added to nine parts of water. For conven-

ience this response will be called an "oil to water ratio effect". The nature of the effect of the oil to water ratio is still under investigation. So far the peak performance has been obtained at an oil to water ratio of between 1:10 and 1:20.

Response of different plants. Plants sprayed in the seedling stage are classified in two categories as to response: (a) The susceptible species are controlled at rates of one pound per acre or less of S–847. (b) The resistant species showed only minor effects at a two pound per acre rate of S–847.

Conditions of this test were—Rates of S–847, 2, 1, ½, ¼ and ⅛#/A. (wild oats was controlled in this test @ ⅛#/A). Spray volume, 10 gallons per acre. Age of plants, 18 days after seeding (oats in 1½ leaf stage). Greenhouse temperature, 60° F. at night 70°–80° F. day. Fertility level, high. Time, March; 1959. A test was made in August, 1959 on most of these same plants. Plant response was similar to that found in the March test except for okra which was more susceptible in August.

The susceptible (controlled at ⅛ to 1 pound) species were: Oats, *Avena sativa;* Wild oats, *Avena fatua;* Wild buckwheat, *Polygonum convolvulus;* Smartweed, *Polygonum pennsylvanicum;* and Moss rose, *Portulaca grandiflora.*

Additional tests on these five susceptible species indicate that oats, wild oats, wild buckwheat and smartweed are readily inhibited by S–847 at rates of ⅛ to ½ pound per acre, whereas moss rose requires about one pound per acre to inhibit growth for one month. More work on the factors influencing the activity of S–847 on these last three species is being carried out.

Resistant (above plants can be selectively controlled with S–847 in stands of the following):

Gramineae: millet, *Setaria italica;* green foxtail, *Setaria viridis;* yellow foxtail, *Setaria glauca;* crabgrass, *Digitaria sanguinalis;* bromegrass, *Bromus inermis;* wheat, *Triticum aestivum;* rye, *Secale cereale;* barley, *Hordeum vulgare;* and corn, *Zea mays.*

Liliaceae: onion, *Allium cepa;* and leek, *Allium porrum.*

Chenopodiaceae: beet and swiss chard, *Beta vulgaris;* spinach, *Spinacea oleracea;* kochia, *Kochia scoparia;* and lambsquarters, *Chenopodium album.*

Nyctaginaceae: four-o-clock, *Mirabilis jalapa.*

Caryophyllaceae: sweet William, *Dianthus barbatus;* pinks, *Dianthus plumarius;* and carnation, *Dianthus caryophyllus.*

Ranunculaceae: larkspur, *Delphinium* sp.

Papaveraceae: California poppy, *Eschscholtzia californica.*

Cruciferae: candytuft, *Iberis amara;* sweet alyssum, *Lobularia maritima;* radish, *Raphanus sativus;* turnip, *Brassica napus;* brussels sprouts, cauliflower, broccoli, cabbage, collards, and kohlrabi, *Brassica oleracea;* wild mustard, *Brassica kaber;* wallflower, *Cheiranthus cheiri;* shepherds purse, *Capsella bursa-pastoris;* and penny-cress, *Thlaspi arvense.*

Leguminosae: alfalfa, *Medicago sativa;* peas, *Pisum sativum;* soy-

beans, *Glycine max;* snapbeans, *Phaseolus vulgaris;* sweetpea, *Lathyrus odoratus;* and hyacinth bean, *Dolichos lablab.*

Tropaeolaceae: nasturtium, *Tropaeolum minus.*

Linaceae: flax, *Linum usitatissimum.*

Balsaminaceae: balsam, *Impatiens balsamina;* and patient Mary, *Impatiens sultani.*

Malvaceae: hollyhock, *Althaea rosea;* okra, *Hibiscus esculentus;* cotton, *Gossypium hirsutum;* and velvet leaf, *Abutilon therophrasti.*

Violaceae: pansy, *Viola tricolor.*

Onagraceae: godetia, *Godetia* sp.; and clarkia, *Clarkia* sp.

Umbelliferae: carrot, *Daucus carota;* and parsnip, *Pastinaca sativa.*

Convolvulaceae: morning-glory, *Ipomoea* sp.

Polemoniaceae: phlox, *Phlox* sp.

Labiatae: salvia, *Salvia splendens.*

Verbenaceae: verbena, *Verbena hybrida.*

Solanaceae: tomato, *Lycopersicum esculentum;* nicotiana, *Nicotiana* sp.; butterfly flower, *Schizanthus hybridus;* and petunia, *Petunia hybrida.*

Scrophulariaceae: snapdragon, *Antirrhinum majus;* and foxglove, *Digitalis purpurea.*

Dipsacaceae: scabiosa, *Scabiosa atropurpurea.*

Cucurbitaceae: pumpkin, *Cucurbita pepo;* squash, *Cucurbita maxima;* summer squash, *Cucurbita moschata;* and cucumber, *Cucumis sativus.*

Campanulaceae: lobelia, *Lobelia* sp.

Compositae: african daisy, *Dimorphotheca* sp.; marigold, *Tagetes patula;* lettuce, *Lactuca sativa;* sunflower, *Helianthus* sp.; aster, *Aster* sp.; cosmos, *Cosmos bipinnatus;* calendula, *Calendula officinalis;* zinnia, *Zinnia elegans;* bachelors button, *Centaurea cyanus;* ragweed, *Ambrosia artemisiifolia;* and ageratum, *Ageratum houstonianum.*

SUMMARY

The optimum time to spray wild oats with 4–chloro–2–butynyl *N*–(3–chlorophenyl)carbamate varies with the growth conditions affecting the plants. 4–Chloro–2–butynyl *N*–(3–chlorophenyl)carbamate controls wild oats at lower rates and over a longer time interval when the wild oats are growing rapidly as a result of high fertilizer rates. Heavy fertilization resulted in a greater percentage of wheat in treated mixtures of wheat and wild oats.

The effectiveness of 4–chloro–2–butynyl *N*–(3–chlorophenyl)carbamate for the control of oats or wild oats is inversely related to spray volume. This effect is not consistent under all conditions of testing.

Five of the 87 kinds of plants on which observations have been made can be controlled by less than one pound per acre of 4–chloro–2–butynyl *N*–(3–chlorophenyl)carbamate. These are *Avena sativa, Avena fatua, Polygonum convolvulus, Polygonum pennsylvanicum* and *Portulaca grandiflora.*

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Measurement of Microbiological Effects of Herbicides[1]

JEAN S. WHITESIDE and M. ALEXANDER[2]

IN considering the interaction between microorganisms and herbicides applied to the soil, two effects may become of great practical significance. One involves the potential inhibition or even germicidal action of the chemical to the microscopic inhabitants of the soil. These organisms, chiefly the bacteria, fungi and actinomycetes, occupy a unique position in biological cycles in terrestrial habitats and are essential for plant growth and soil fertility. The microorganisms decompose root and crop residues, mobilize the reserve of organic nitrogen and phosphorus, carry out transformations involving a change of oxidation state and bring about many other reactions necessary for crop production. Any deleterious influence, even of a temporary nature, could have a profound effect upon crop yields.

A second interaction between herbicides and microorganisms is the alteration of the chemicals through the physiological activities of the microflora. The application of organic compounds typically stimulates specific organisms to develop, utilizing the applied material to support proliferation and, as a consequence, leading to the total disappearance of the weed-killing agent.

Two simple and rapid techniques have been developed to assess the significance of these interactions: (1) a manometric measurement of the effect of the herbicides on the microflora and (2) a spectrophotometric procedure to determine the influence of the organisms on the chemical. The former is of general application while the latter is limited to aromatic molecules.

METHODS AND MATERIALS

For the manometric measurement of herbicidal toxicities, the Warburg microrespirometer was utilized. Each respirometer flask received 4.0 gm soil (Honeoye silt loam) moistened with 1.2 ml distilled water. The chemical, and in some studies 1.0 mgm glucose, were added in the water which was spread evenly over the soil surface. The center well of each vessel contained 0.2 ml 20 per cent KOH and a filter paper strip, and oxygen consumption was measured at 30° C using conventional manometric procedures (9). The compounds tested include 2,4–dichlorophenoxyacetic acid (2,4–D), 2–(2,4–dichlorophenoxy)propionic acid or 2–(2,4–DP), 4–(2,4–dichlorophenoxy)butyric acid or 4–(2,4–DB), 2,4,5–trichlorophenoxyacetic acid (2,4,5–T) and 3–amino–1,2,4–triazole (amitrol). Quantities of these chemicals are supplied in terms of the acid equivalents although

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all herbicide solutions were added following neutralization with alkali.

To demonstrate the decomposition of several phenoxy herbicides by the soil flora, the disappearance of the compound was observed by measuring the loss of its specific ultraviolet absorption. The absorption spectra of the herbicides 2,4–D, 2–(2,4–DP), 4–(2,4–DB), 2,4,5–T, 2–(2,4,5–trichlorophenoxy)propionate, abbreviated as 2–(2,4,5–TP), and 4–(2,4,5–trichlorophenoxy)butyrate or 4–(2,4,5–TB) at a concentration of 0.001% were determined on the Beckman spectrophotometer, model DU, in the ultraviolet. The 2,4–D, 2–(2,4–DP) and 4–(2,4–DB) were determined to have a peak at about 283 mμ., and 2,4,5–T, 2–(2,4,5–TP) and 4–(2,4,5–TB) had an absorption maximum at 288. The optical density of these compounds at the wavelength of maximum absorption is directly proportional to the concentration between 0–100 μg/ml. This is in agreement with the data of Dorschner and Buchholtz (1).

To trace the decomposition pattern of the six herbicides, Erlenmeyer flasks containing 200 ml of a mineral-salt medium plus the herbicide at a final concentration of 30 μg/ml were incubated at 30° C on a rotary shaker. The medium contained 0.5 gm NH_4NO_3, 0.8 gm K_2HPO_4, 0.2 gm KH_2PO_4, 0.2 gm $MgSO_4 \cdot 7H_2O$, 0.03 gm $FeSO_4$ and 0.10 gm $CaCl_2 \cdot 2H_2O$ in 1.0 liter of distilled water. The flasks were inoculated with 4.0 gm of freshly sampled Honeoye silt loam, and an initial recording of the optical density was taken after three hours. The three dichlorophenoxy alkylcarboxylic acids were measured at 283 mμ and the 2,4,5–T compounds at 288 mμ.

At regular intervals, a 10 ml aliquot was removed from each flask and centrifuged at 3400 X G for two minutes, and the optical density of the supernatant was measured against a blank of distilled water. If decomposition had occurred and the compound was no longer detectable, fresh increments of the herbicides were added to bring the concentration up to 60 μg/ml. The optical density in the test solution was corrected for ultraviolet absorption by soluble soil constituents by subtracting the optical density at the same wavelength of an herbicide-free medium inoculated with 4.0 gm soil and carried through the same incubation.

To establish whether the decomposition of 4–(2,4–DB) proceeded through 2,4–D, the medium containing either the acetic or butyric derivative was sterilized by filtration and inoculated with 1 ml of 2,4–D or 4–(2,4–DB) enrichments obtained from herbicide–soil culture flasks described above. The initial herbicide concentration was 60 μg/ml. In addition to inoculating the two enrichments into fresh media containing the same organic substrate, the 4–(2,4–DB) enrichments were inoculated into 2,4–D media, and the 2,4–D enrichments were seeded into the 4–(2,4–DB) solutions. The optical density of the inoculated flasks was determined spectrophotometrically as described.

To illustrate the technique further, a study was made of the influence of pH on 4–(2,4–DB) breakdown. The herbicide-containing medium having approximately 60 μg/ml of the organic compound

was adjusted to a range of pH values, inoculated with 2 ml of a 3-month old 4–(2,4–DB) enrichment culture, and the optical density of the media read at 283 mμ at regular time intervals.

RESULTS AND DISCUSSION

The procedure adopted for measurement of herbicide effects on the soil microflora involves the measurement of O_2 consumption although the release of CO_2 during the decomposition undoubtedly would give the same general results. The influence of the chemical applied at various concentrations to the soil under study is compared to the respiration of the population in the absence of the chemical. The patterns obtained in periods of several hours were the same as those observed in trials of several days duration so the shorter period was utilized. Some typical results are presented in Table 1.

Table 1. **Effect of several herbicides on soil respiration.**

Herbicide	Glucose mgm	Time hours	μL O_2 uptake/hr at herbicide concentrations[a] of			
			0 ppm	10 ppm	100 ppm	250 ppm
2,4-D	0.0	4.0	19.0	21.0	14.5	15.0
2,4-D	1.0	4.0	31.3	31.0	33.0	21.5
2,4,5-T	0.0	8.5	21.6	20.8	22.9	16.4
2,4,5-T	1.0	6.5	37.7	40.0	36.2	29.2
2-(2,4,DP)	0.0	3.7	14.2	15.5	15.2	15.0
4-(2,4-DB)	0.0	9.1	16.0	15.7	15.7	13.3
Amitrol	1.0	8.0	32.8	33.3	30.8	24.8

[a]Herbicide concentration on soil weight basis.

Concentrations of 2,4–D up to 100 ppm had no effect on the decomposition of the added carbohydrate although a marked depression was noted in the oxidation of the native soil organic fraction. The differences in the two treatments are associated with the activity of the indigenous and the zymogenous microorganisms and indicate a greater sensitivity of the former to high levels of application. No depression was detected for either group at field rates of application. At 250 ppm. or more, 2,4–D inhibited both the unamended and the glucose-treated soil. The results with 2,4,5–T are generally the same except for the absence of a depression of humus decomposition at 100 ppm of the herbicide. With this compound, the 250 ppm level produced a marked microbial toxicity. Figure 1 illustrates the data from one trial with 2,4,5–T, demonstrating the close fit of the O_2 uptake at 0 and 100 ppm applications of 2,4,5–T and the definite depression by 250 ppm.

In contrast, there was no evidence of suppression by 2–(2,4–DP) even at the highest concentration used. The effect of 4–(2,4–DB) was similar to that of the propionic derivative except for a slight inhibition at a rate of 250 ppm, a suppression of the order of 15 per cent. Amitrol at rates up to 100 ppm was also without significant influence upon the organisms participating in the decomposition of the sugar.

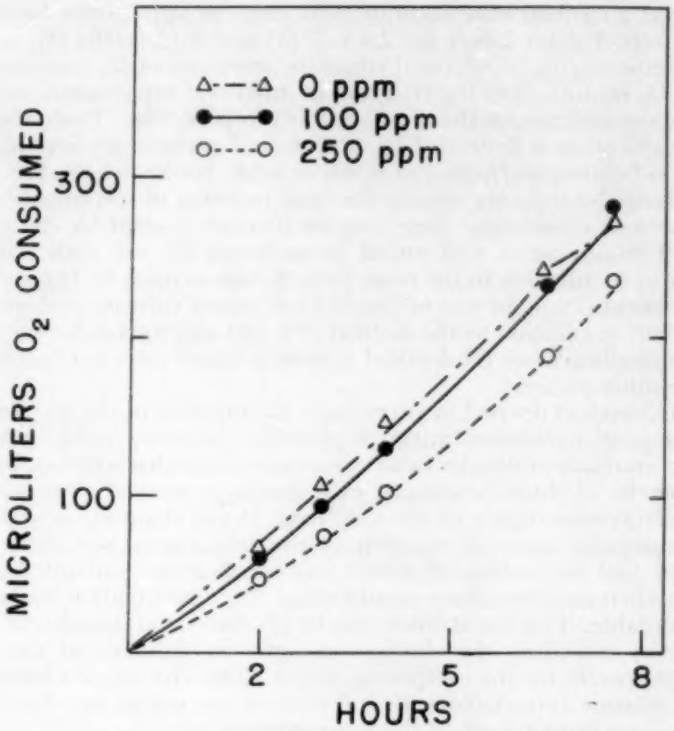

Figure 1. Oxygen consumption in soils treated with glucose and varying concentrations of 2,4,5–T.

The greater oxygen consumption by the microorganisms in soils treated with glucose has a distinct advantage since it permits a greater accuracy in the determination of microbial respiration, and inhibitions are more distinct. The results obtained by this procedure confirm observations made by other methods, that is a lack of inhibitory effects at recommended application rates and the need for excessive amounts for toxicity to become significant. However, with new chemicals continually coming into use and with the need to ascertain differences in microbiological response between soil types, treatments and environmental conditions, a convenient and rapid technique such as this manometric method has certain distinct advantages.

The manometric technique for determining the effect of herbicides on the respiration of the soil microflora is simple, inexpensive and rapid. A single individual can determine with ease the influence of many environmental variables. Those include varying soil types, herbicide concentrations, organic and inorganic amendments, etc. The results are in agreement with the data obtained by procedures requiring several weeks of incubation and numerous determinations.

Lack of microbial inhibition by field levels of application have also been reported for 2,4–D (4), 2,4,5–T (5) and 4–(2,4–DB) (3).

A serious criticism of the method lies in its use of O_2 consumption (or CO_2 evolution) as the criterion of microbial suppression, as these processes may not be the most sensitive to pesticides. Thus, the rate of nitrification is depressed by as little as 2 pounds per acre of amitrol and correspondingly low levels of other herbicides (6). Since the nitrifying bacteria are among the least resistant of soil organisms to deleterious conditions, these may be directly studied by the manometric technique as well, either by enriching the soil with nitrifiers prior to its addition to the respirometer flask as done by Quastel and Scholefield (7), or by use of liquid enrichment cultures and measuring their respiration by the method of Engel and Alexander (2). With these modifications, the method may be adapted even to these highly susceptible bacteria.

The method devised to investigate the capacity of the soil flora to decompose halogen-substituted phenols, phenoxy compounds or other aromatic molecules takes advantage of the characteristic optical properties of these substances, each having a marked absorption in the ultraviolet region of the spectrum. If the chemical is added to an inorganic nutrient solution as the sole source of carbon, soil added, and the soil-liquid system incubated under controlled conditions, then decomposition should occur if the herbicide is biologically available. This breakdown can be observed and accurately measured by recording the changes in light transmission at the wave length specific for the compound in question. The use of a herbicide-free solution inoculated with soil permits correction for ultraviolet-absorbing constituents of the humus fraction.

When 2,4–D was added to the medium and inoculated with the Honeoye silt loam, the disappearance of the compound was readily apparent (Figure 2), and the optical density fell to almost the control level in about 10 days. Subsequent additions were metabolized in even shorter time intervals. In the oxidation of 4–(2,4–DB), on the other hand, a significant lag period was apparent before appreciable loss of the chemical could be detected. The lag is followed by a stage of rapid growth until all the herbicide is metabolized by the end of the second week. Here too, the supplemental increments were transformed in shorter periods than the initial quantity since the solution has become enriched with the active population. The results in Figure 2 indicate that 2–(2,4–DP) is resistant to attack, and no loss was found even in 116 days with this soil.

The curves show how it is possible to determine which pesticides are degraded biologically and how individual rates can be compared. The biological nature of the transformation is evident by the presence of the lag followed by the active stage and the fact that subsequent additions are acted upon in even shorter time intervals. The lack of a lag period upon retreatment is due to the system becoming populated with the appropriate microorganisms by the first treatment.

Under identical conditions, there was no evidence for the break-

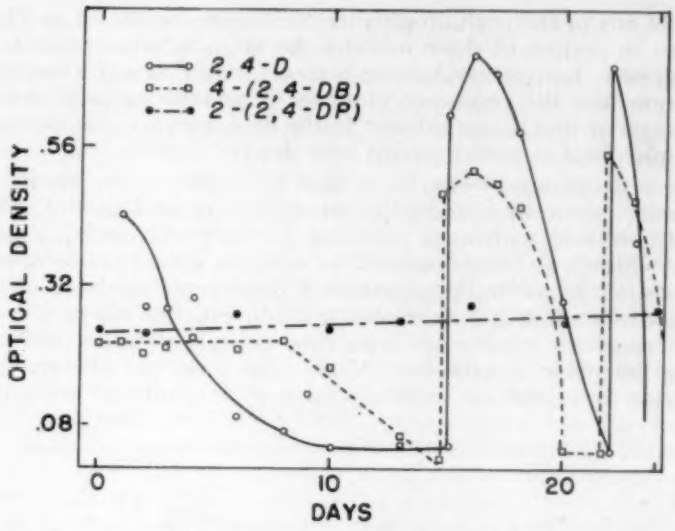

Figure 2. Spectrophotometric determination of the decomposition of 2,4–D, 2–(2,4–DP) and 4–(2,4–DB).

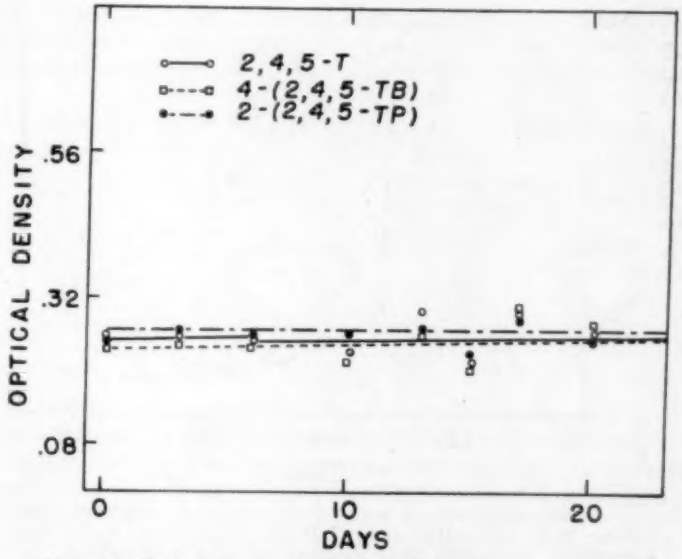

Figure 3. Resistance to microbial decomposition of 2,4,5–T, 2–(2,4,5–TP) and 4–(2,4,5–TB).

down of any of the trichlorophenoxy derivatives as shown in Figure 3. Even in periods of three months, the aromatic absorption failed to disappear. Longer incubation, however, might reveal a biological oxidation, but the resistance to attack is nonetheless well defined. This suggests that disappearance in the field is either non-biological or, if microbial in nature, occurs very slowly.

The procedure may also be utilized in studies of the mechanism of decomposition by mixed populations such as are found in nature. If soil is treated with some chemical A, there will occur an initial period wherein no breakdown can be detected, then a period of rapid degradation. In natural populations A is not transformed to its final product by a single species, rather it is converted to one of a variety of intermediate compounds involving entirely different microbial groups for their metabolism. These substances are the naturally occurring intermediates and should not be confused with those

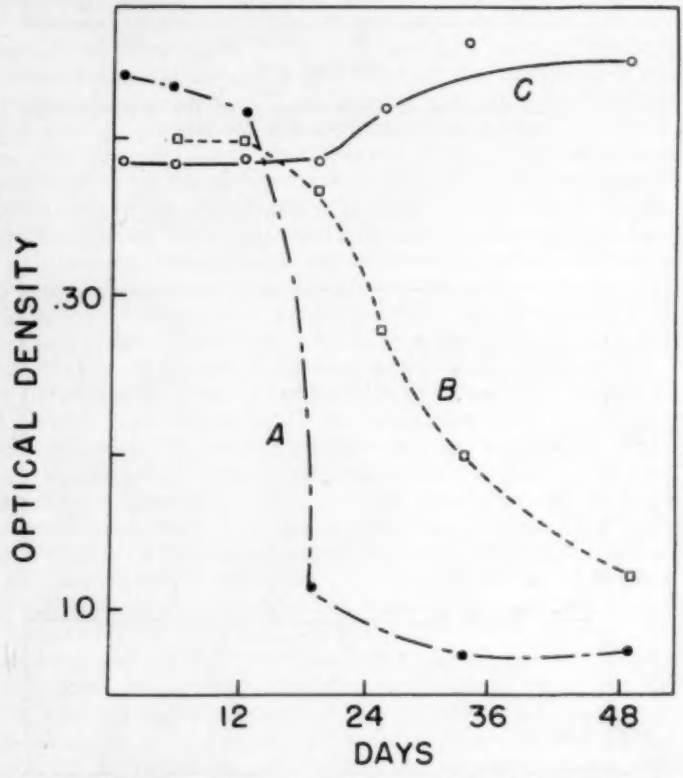

Figure 4. Decomposition of 4-(2,4-DB) and 2,4-D following subculture from 4-(2,4-DB) and 2,4-D enrichments. A: 4-(2,4-DB) enrichment inoculated into medium of same composition. B: Same inoculated into 2,4-D medium. C: 2,4-D enrichment inoculated in 4-(2,4-DB) medium.

biochemical intermediates that rarely accumulate in significant quantities outside of the organism.

Adapting Stanier's (8) hypothesis of simultaneous adaptation from pure cultures to mixed populations, it would seem that if B is a naturally occurring intermediate in the conversion of A to its end-product D, then B will have been formed in the oxidation of A, and the addition to soil of A will build up both an A-decomposing and a B-decomposing population. Therefore, since the secondary flora has been simultaneously enriched, the decomposition of B by the microflora of a soil previously treated only with A should proceed without the long lag period. A compound C, not an intermediate, will require the lag since these organisms have not been simultaneously enriched.

Experiments to test the application of this approach to herbicides were initiated with 2,4–D and 4–(2,4–DB). The results are shown in Figure 4. When 4–(2,4–DB) enrichments were inoculated into nutrient solutions containing either 4–(2,4–DB) or 2,4–D, both were quickly metabolized. On the other hand, 2,4–D enrichments caused the disappearance of 2,4–D but not the butyric acid derivative. Thus, development of a population that degrades 4–(2,4–DB) provides for a simultaneous increase in the abundance of organisms active on 2,4–D, suggesting that 2,4–D is an intermediate in the destruction of the butyric form. This would probably involve a beta-oxidation of the aliphatic moiety similar to that described for fatty acids.

The spectrophotometric technique for measurement of the decomposition of aromatic molecules may also be used in ascertaining the influence of environmental variables. The effect of hydrogen ion concentration is one of the more important of such ecological influences, and some data illustrative of the use of the method applied to the significance of pH is shown in Table 2 for 4–(2,4–DB). The

Table 2. Effect of pH on the breakdown of 4–(2,4–DB) by soil enrichment cultures.

Days	Optical density at pH				
	4.5	5.6	6.5	6.8	7.8
0	0.230	0.260	0.340	0.330	0.298
5	.310	.335	.335	.325	.300
12	.315	.048	.090	.310	.285
19	.165	.025	.065	.040	.072
33	.075	.068	.080	.070	.072
Final pH	5.2	5.8	6.6	6.9	7.4

initial increase in optical density is not infrequent and probably results from the release of ultraviolet-absorbing constituents from soil organic matter. The decomposition was appreciable at most pH values by the end of the second week and was essentially complete at all except the most acid reaction by the 19th day. It would seem, therefore, that the population active on this compound is capable of functioning over a wide pH range although the rate is somewhat slower in more acid conditions.

The advantages of the spectrophotometric technique lie in its ease of manipulation and the minimum of space and manpower required. The need for prolonged plant bioassays is eliminated, and the number of experimental variables and replications may be increased many fold. The method permits the determination of the compounds which are degraded biologically, allows for a comparison of rates and shows the environmental factors which affect the transformation. It is, however, limited to compounds with a marked light absorption in some region of the spectrum and requires that the breakdown proceed to a point where the absorption diminishes or disappears. In the work reported, it would seem that the method would only detect decomposition if a ring cleavage were involved and would not show changes taking place in the aliphatic portion of the molecule. Studies of 3,4–dichlorophenoxyacetic, 2–methyl–4–chlorophenoxyacetic and 4–chlorophenoxyacetic acids and related phenoxyalkylcarboxylic acids as well as a number of halogen substituted phenols indicate that the decomposition of these substances may also be detected in this way (Alexander and Aleem, unpublished data).

The simultaneous adaptation approach to decomposition by mixed populations seems a useful first approximation to the pathway of breakdown of organic substrates in soil, but it cannot in any way replace conventional chemical and biochemical techniques. Several shortcomings are readily apparent, chief of which is the fact that enrichment of the secondary population (B microorganisms) by the addition of substrate A does not necessarily prove that B is an intermediate since the B microflora may be capable of metabolizing rapidly a number of compounds both related and unrelated to the true intermediate. The technique does, however, give a means of narrowing down the number of possible substances that may be produced.

The results suggest that 4–(2,4–DB) is probably transformed in soil by way of 2,4–D and that soils receiving the former would have a flora active on the latter as well. Webley, Duff and Farmer (10, 11), have demonstrated by use of actinomycetes of the genus *Nocardia* that 4–phenoxybutyric, 4–(3–chlorophenoxy)butyric and 4–(4–chlorophenoxy)butyric acids are converted to the corresponding acetate derivatives. It would thus seem that the metabolism of these compounds in soil agrees with that observed in pure culture, that is, the removal of a C_2 fragment from the aliphatic side chain.

SUMMARY

A method is described for measurement of the effect of several herbicides on soil respiration using oxygen consumption in the decomposition of native soil organic matter or added carbonaceous materials as the criterion. No microbiological effect could be found at rates of application corresponding to those used for weed control.

By measurement of the changes in ultraviolet absorption of herbicide solutions inoculated with soil, it has been shown that 4–(2,4–

dichlorophenoxy)butyric acid and 2,4–dichlorophenoxyacetic acid are metabolized by the soil microflora, and the possibility of the latter being formed in soil from the former is suggested. No evidence has been found for a microbiological attack of 2,4,5–T, 4–(2,4,5–TB), 2–(2,4,5–TP) and 2–(2,4–DP) sufficient to cause a disappearance of the ultraviolet absorption. The advantages of the spectrophotometric technique for measuring microbiological decomposition of aromatic herbicides are considered, and several specific applications are illustrated.

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A Tabular Summary of Research Dealing with Translocation of Foliar-Applied Herbicides and Selected Growth Regulators

HERBERT M. HULL[1]

THE table briefly summarizes research findings involving the translocation of organic herbicides and certain selected growth regulators in higher plants. Gibberellic acid, indoleacetic acid, naphthaleneacetic acid and other "non-herbicide" growth regulators are for the most part not listed except when used in experiments with the more generally accepted herbicides. For tabular information on translocation of auxins and other growth substances, the reader is referred to the Handbook of Biological Data, mentioned later. Information in the table is based on techniques which primarily utilize foliar application and for the most part does not include application via root system, injection, or bark application. As a consequence, most substances listed may be assumed to be transported predominantly in the phloem, but in numerous cases the compounds also move into the xylem.

Many organic substances applied to a plant are broken down to different metabolic products within the plant. However, an increasing number of recent studies (made possible largely by radiochromatography) indicate that a significant portion of most organic materials may be translocated within the plant in the same molecular form in which it was applied. Consequently, for simplification of tabulation, the materials listed in the "Substance" column are considered to be those applied to the plant.

As to the "Translocation direction" column, acropetal (A) or basipetal (B) may be defined as movement in a morphologically upward or downward directon, respectively. It should be stressed, however, that the direction shown is specific only for the experiment described and may vary according to growth stage, concentration of substance applied, technique of application, etc.

Translocation rate, if given under "Remarks", was either specified by the investigator or calculated from data presented. Such rates do not necessarily represent maximum or even mean values for the conditions of the experiment; in many instances they were simply based upon the time (after treatment) at which harvest or assay of specific plant parts happened to take place. In most experiments, the time factor upon which rate is based includes time of absorption from cuticular surface to phloem. Although certain techniques eliminate the absorption factor, true translocation rate within the phloem may well be greater than the figures given in many cases.

Wherever several plants and herbicides are listed under a single entry it does not necessarily follow that all herbicides were tested

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on all plants; or in the case of entries with multiple references, that all plants and compounds listed are considered in every reference. In addition, it should not be assumed that a chemical is readily translocated because it appears in the table. In some cases, as may be noted, only traces were transported.

If the results of a specific piece of research were reported in several journals, only the most recent, the most comprehensive, or that published in one of the more readily obtainable journals was cited. The numerous publications on translocation in reports of the regional weed control conferences of the United States were not cited.

By permission of the Editor of the Handbook, citations in the present table are largely from tables on "Translocation of organic substances: Plants", which the author recently compiled for the Handbook of Circulation, a monograph which complements the Handbook of Biological Data, edited under the auspices of the National Research Council. These tables include (1) Assimilates and carbohydrates; (2) dyes; (3) herbicides and growth regulators; (4) viruses; (5) alkaloids; (6) flowering stimuli; (7) nitrogenous substances and vitamins.

Although the objective of the present table was to present a fairly complete coverage of literature available to the author through 1958, it is entirely possible that some pertinent papers may have been inadvertently overlooked.

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FOOTNOTES

The following footnotes identify herbicides which have been assigned common names by the Terminology Committee of the Weed Society of America, and have been listed by those names in the table. Only the first entry of each compound has been identified.

[1]Stem
[2]Leaf
[3]2,4–Dichlorophenoxyacetic acid
[4]2,4,5–Trichlorophenoxyacetic acid
[5]3–Amino–1,2,4–triazole
[6]1,2–dihydropyridazine–3,6–dione (maleic hydrazide)
[7]3–(*p*–Chlorophenyl)–1,1–dimethylurea
[8]2,2–Dichloropropionic acid
[9]2,3,6–Trichlorobenzoic acid
[10]2,3,5,6–Tetrachlorobenzoic acid
[11]2,2,3–Trichloropropionic acid
[12]Ammonium sulfamate
[13]4–Chlorophenoxyacetic acid
[14]Isopropyl *N*–phenylcarbamate
[15]Trichloroacetic acid
[16]2,5–Dichlorophenoxyacetic acid
[17]3,4–Dichlorophenoxyacetic acid

Entry No.	Plant name	Plant part	Substance	Translocation direction	Remarks	Reference No.
1	Alligator weed (*Alternanthera philoxeroides*)	Leaf Stem	2,4–D[3]	A[1],B[1,2]	C^{14}-labeled 2,4–D applied to 1 pair leaves. Stems sectioned and extracted for activity determinations 8 or more hr. after treatment. Acropetal movement in stem more extensive and slightly more rapid than basipetal. Rate of movement 4.2–4.3 cm per hr.	26
2	Aspen, quaking (*Populus tremuloides*)	Leaf Stem Root	2,4,5–T[4]	A[1,2],B[1]	Application of 2,4,5–T in diesel oil to the intact stem of a 5-year-old seedling, or to the stem just below a girdle, killed the entire plant within 3 weeks. Application just above a girdle killed the upper part of the seedling but had no effect below the girdle, suggesting basipetal movement in phloem only.	78
3	Autumn-Crocus (*Colchicum autumnale*) Buttercup (*Ranunculus* sp.) Chickweed (*Stellaria media*) Dandelion (*Taraxocum* sp.) Mustard, white (*Brassica hirta*) Orache (*Atriplex patula*) Pigweed (*Chenopodium album*)	Leaf Stem	2,4–D	A, B	Transport in orache and pigweed initially basipetal and later acropetal. Sensitivity to a second 2,4–D application was variable among different plants and dependent upon length of time since first application.	53
4	Barley (*Hordeum vulgare*) Bean (*Phaseolus vulgaris*) Cucumber (*Cucumis sativus*) Maize (*Zea mays*) Sunflower (*Helianthus annuus*)	Stem Root	2–methyl–4–chlorophenoxy–acetyl derivatives of amino acids; amide, lactic acid, and terpenoid derivatives of substituted phenoxy–carboxylic acids	A	Translocation determined by measurement of stem curvature, epinasty, formative effect, cellular proliferation, and growth repression at intervals of 2 to 14 days after application to basal portion of stem in lanolin or to soil surface in a sand slurry. A few of the derivatives were more active than the parent herbicides; most were less active. Many compounds were synthesized and tested.	48, 49
5	Barley Bean Cucumber Maize Sunflower Tomato (*Lycopersicon esculentum*)	Leaf Stem	α–methoxy–phenylacetic acid	A, B	Applied to stem (dicots) or leaf (monocots), the compound caused epinasty or repression of terminal growth. Although phenylacetic acid produces a gall at the site of the application in bean, it does not produce a secondary gall at the internode above, as does the compound listed. Movement from roots of one plant to roots of a second plant within 9 hr. was noted.	63, 71
6	Barley Bermudagrass (*Cynodon dactylon*) Cotton (*Gossypium* sp.) Maize Wandering Jew (*Tradescantia fluminensis* and *Zebrina pendula*)	Leaf Stem Root	2,4–D; 2,4,5–T; amitrol[5]; MH[6]; monuron[7]; dalapon[8], sodium salt; urea	A, B	Translocation determined by autoradiography and by counting at various intervals after application of C^{14}-labeled compound to one or several leaves or to stolons. Movement of 2,4–D restricted by absorption in phloem, but absorption minimized in rapidly growing plants. Other compounds translocated throughout plants to a greater extent, some moving in the phloem, others also entering xylem or moving predominantly in xylem. None moved out of chlorotic leaves. Dalapon, MH, and amitrol were highly motile. Radiochromatography demonstrated very slow metabolic degradation of dalapon.	17, 19, 20, 21, 87

7	Barley Oats (*Avena* sp.)	Leaf Stem Root	2,4-D	A, B	Autoradiography of various-aged barley plants harvested 4–8 hr. after application of C^{14}–labeled 2,4–D to the center of each leaf, demonstrated that plants having 1–3 leaves transported C^{14} to the roots whereas those with 5–6 leaves did not. Oats showed little transport to the roots at either the 1–2 or the 5–6 leaf stage, but did demonstrate marked transport to all plant parts when treated at the 3–4 leaf stage.	70
8	Barley Oats Ryegrass (*Lolium* sp.) Tall fescue (*Festuca arundinacea*)	Leaf Stem	lactic acid *N*–phenyl-carbamate and lactic acid *N*–(3–chloro-phenyl) carbamate	A^1,B^2	Application to first leaf, with measurement of subsequent repression of young leaf growth. Lactic acid compounds translocated to a greater extent than corresponding isopropyl compounds, lactic acid molecular configuration apparently being advantageous to translocation.	62
9	Barley Tomato	Leaf Stem	2,3,5–triiodo–benzoic acid	B	Autoradiography of plant 24 hr. after application of I^{121}– labeled compound to a mature leaf showed absorption in both species, but translocation to a lower primary leaf limited to tomato. Radiochromatography demonstrated that compound moved essentially in an unchanged form.	66
10	Bean	Leaf Stem	2,4–D and 2,4,5–T, various butyl, octyl, and octadecyl esters	A^1,$B^{1,2}$	Application to one primary leaf, with resultant stem curvature measured after 4 hr. During this time only illuminated plants developed curvature. Temp. 21–24°C.	54
11	Bean	Leaf Stem	2,4–D and a 2,4–D complex	B	C^{14}–labeled 2,4–D applied to veins of one leaf of etiolated plants, activity being determined in sections made 4 days later. Addition of glucose or sucrose to the 2,4–D enhanced movement of the latter, but glucose–1–phosphate did not.	47
12	Bean	Leaf Stem Root	2,4–D	A, B	Methylene C^{14}–labeled 2,4–D applied to midrib of one primary leaf. Plants sectioned 2–144 hr. after application and activity determined. Activity in apical bud after 8 hr. but no movement occurred into leaf opposite to that treated.	31
13	Bean	Leaf Stem Root	2,4–D and 2,4,5–T, sodium salt	B, principally	Applied to one primary leaf in a carrier of pH 8, 4 hr. was required for the epicotyl to bend. Two hr. was required at pH 2. Rate of movement 50–100 cm per hr.	14
14	Bean	Leaf Stem Root	2,4–D	B^2	Applied to leaves, and determined in various plant parts by bio-assay. No transport from leaves of plants kept in dark 18–24 hr. prior to and during treatment. Sucrose facilitated movement; mannitol did not. Low temperatures reduced transport.	39
15	Bean	Entire plant	2,4–D	A, B	Primary leaves severed 24 hr. after application of 2,4–D, and entire remainder of plant extracted. Presence of unaltered 2,4–D determined by bio-assay of the extract and by chemical characterization.	83
16	Bean	Leaf Stem	2,4–D	A^1, B^2	Application of 2,4–D directly to the apical bud caused a growth repression independent of temperature in the range of 22–34°C. Application via a primary leaf resulted in maximum repression of apical bud and leaf expansion at the lower temperature.	81

Entry No.	Plant name	Plant part	Substance	Translocation direction	Remarks	Reference No.
17	Bean	Leaf Stem	2,4–D	A[1], B[2]	Application of 2,4–D to a primary leaf caused epicotyl curvature to appear more rapidly at 35° than at 25°C, but maximum angle of curvature was 60 percent greater at the lower temperature. Rate of transport 13–106 cm per hr.	23
18	Bean	Leaf Stem Root	2,4–D and derivatives thereof	A, B	Translocation determined by autoradiogram, stem curvature, and apical leaf growth repression after application to one primary leaf. Kerosene served well as a carrier for 2,4–D in destarched plants, and appeared to move through intercellular spaces of phloem parenchyma. Translocation rate 4 cm per hr.	74
19	Bean	Leaf Stem	2,4–D, ammonium salt	A[1,2], B[2]	Primary leaf excised 4–72 hr. after application of 2,4–D and fresh weight of apical leaves determined after 9 days. Increased translocation rate out of leaf at high light intensities.	73
20	Bean	Leaf Stem	2,4–D	A[1],B[1,2]	Content of 2,4–D in various plant parts determined by bio-assay after application to a primary leaf. Entered epicotyl in 6 hr. but would not move below center of hypocotyl. Transport inhibited in case of second application or too high a concentration, because of phloem destruction. Sucrose did, but mannitol and urea did not enhance transport in dark.	42
21	Bean	Leaf Stem Root	2,4–D	A[1],B[1,2]	Radioassay of stem and roots after application of C^{14}–labeled 2,4–D to primary leaf showed activity in 6 hr., with transport chiefly basipetal. After one week, about a third of C^{14} in stem was still in 2,4–D, much of remainder being in an unknown water-soluble acid.	43, 44
22	Bean	Leaf Stem	2,4–D (Also water)	B	Labeled 2,4–D did not move rapidly downward through steam-girdled petioles as did labeled water. This fact, along with ability of water to move out of carbohydrate-depleted leaves (2,4–D does not), renders improbable a mass movement of 2,4–D and water in phloem.	11
23	Bean	Leaf Stem	2,4–D		Pretreatment with gibberellic acid (GA) 48 hr. before 2,4–D application increased amount of 2,4–D in untreated plant parts after several days. GA apparently affects translocation rather than absorption or degradation of 2,4–D.	3
24	Bean	Leaf Stem	2,4–D, morpholine salt; β–hydroxyethyl–4–chlorophenoxyacetate; p–chlorophenyl–2,4,5–trichlorophenoxyacetate; 2–bromo–3,5–dichlorobenzoic acid; (2,4–dichlorophenoxyacetyl) urea; 3–indoleacetic acid	A, B	Listed substances were all translocated, as detected by stem bending after application to one primary leaf. Sucrose, glucose, fructose, maltose, lactose, and galactose all caused 2,4–D to translocate out of a predarkened leaf when applied simultaneously with 2,4–D.	82

			3-indoleacetic acid			
25	Bean	Leaf Stem	2,4-D, ammonium salt; 2,4,5-T; α-naphthalene-acetic acid; 3-indoleacetic acid	B	Movement from primary leaf to stem determined by C^{14} activity in the latter (using C^{14}-labeled 2,4-D), or by stem curvature. Boron applied to the tip of the treated leaf failed to affect translocation, as did a sugar. Boron added to the sugar markedly increased translocation of growth substances.	60
26	Bean	Leaf Stem Root	2,4-D and 3-indoleacetic acid	A^1,$B^{1,3}$	Activity determined in various plant parts after application of C^{14}-labeled indoleacetic acid (IAA) to primary leaf. 10–14 percent of activity transported out of a treated leaf in 14 days, but activity in petiole thereof and lower stem reached maximum after 1 day. Activity in terminal bud reached maximum after 7 days. 2,4-D moved out of treated leaf more rapidly than IAA.	29
27	Bean	Leaf Stem Root	2,4-D, triethanolamine salt; and benzoic acid	B	Transport, determined by autoradiography and counting, was maximum at high temperature (30° over 20°C) and high humidity (72 percent over 36 percent). Maximum effect at high humidity correlated with large stomatal openings.	69
28	Bean	Leaf Stem Root	2,4-D; amitrol; MH	A,B	Repression of growth above primary leaves and autoradiography of freeze-dried plants at various intervals after treatment of one primary leaf were used as an index of translocation. Plants were also sprayed. Certain surfactants markedly enhanced results, depending upon method of treatment. Silicone was a good carrier for 2,4-D, and the most effective formulation of 2,4-D was a function of concentration. MH and amitrol translocated more freely than 2,4-D.	51
29	Bean	Leaf Stem	2,4-D; 2,3,5-triiodobenzoic acid; α-methoxyphenyl-acetic acid; 3-indole-acetic acid; gibberellic acid	A^1, B^2	Translocation studied by applying compound to primary leaves and chromatographing extract obtained from first internode 2–7 days later. Eluate from chromatogram, along with known compounds, was then applied to first internode in order to compare resultant growth repression and epinasty.	79
30	Bean	Leaf Stem Root	2,4-Dichloro-5-iodophenoxy-acetic acid and 14 derivatives thereof	A^1,$B^{1,3}$	I^{131}-labeled compounds applied to leaves, stems, and roots. Movement from leaf to stem (determined by curvature of the latter) occurred only if plant was maintained in the light. As a spray, I^{131}-labeled 2,4-D-5-I was less toxic than 2,4-D.	57
31	Bean	Leaf Stem Root	2,4-dichloro-5-iodophenoxy-acetic acid, free acid and morpholine salt	A, B	Various plant portions assayed for I^{131} 3 days after application of the labeled compound to one primary leaf. Concentration in the stem significantly greater with the acid than with the morpholine salt, and markedly increased by addition of a wetting agent.	61
32	Bean	Leaf Stem Root	amitrol	$A^{1,2}$$B^{1,2}$	C^{14}-labeled compound applied to primary leaves moved basipetally in stem during first 24 hr., but radiochromatography of plant sections after 5 days showed C^{14} concentrated in terminal bud and aminotriazole converted to two unknowns. Only 7 percent of total activity remained as amitrol by fifth day, and about half of activity had moved out of treated leaves.	72

Entry No.	Plant name	Plant part	Substance	Translocation direction	Remarks	Reference No.
33	Bean	Leaf Stem Root	monuron	A, B	One leaf was treated with the C^{14}-labeled compound and plant was sectioned for assay of activity 2–72 hr. after treatment. Translocation was observed throughout plant, maximum concentration in nontreated leaves occurring only by fourth day.	30
34	Bean	Leaf Stem Hypocotyl	2-iodo-3-nitrobenzoic acid	A, B	I^{131}-labeled compound applied to first true leaf. Sections, taken 3 days later, indicated activity accumulation in the apical bud and hypocotyl.	86
35	Bean	Leaf Stem Root	2,3,6-TBA[9] and 2,3,5,6-TBA[10]	A, B	Application to first internode, cotyledon, or primary leaf resulted in movement to the root, through soil, and into adjacent plants, as determined by growth modification. Transport from leaf to stem took 4 hr. Other chlorinated benzoic acids did not affect adjacent plants.	55
36	Bean	Leaf Stem Root	α-methoxy-phenylacetic acid	B	Radioassay of nutrient culture solution after application of C^{14}-labeled compound to primary leaves showed accumulation in original molecular form, reaching maximum after 126 hr. Decreased nutrient aeration or severing part of roots decreased exudation into nutrient, but exudation later increased after severed roots renewed growth.	56
37	Bean	Leaf Stem	2,4- and 3,4-dichlorobenzyl-nicotinium chloride; parachlorobenzyl-nicotinium chloride; other nicotinium compounds	A[1],B[2]	Translocation indicated by percentage reduction in stem elongation 10 days following treatment of specific parts, as follows: first internode, 34 percent; hypocotyl, 23 percent; leaves, 7 percent; cotyledon, no reduction. 2,4- compound most effective, and young plants most sensitive.	64
38	Bean Bindweed, field (*Convolvulus arvensis*) Cowpea, var. Black-eyed (*Vigna sinensis*) Cotton Cucumber	Leaf Stem Root	2,4-D (acid, amine, ester, and sodium salt formulations)	A,B	Transport determined by autoradiography at intervals of 15 min. to 144 hr. after application to specific cotyledons or leaves. 2,4-D reached bean roots in 3 hr. and terminal bud in 6 hr., and moved out of cotyledons or basal leaves more rapidly than young leaves. It was transported with assimilates, and may move in water-stressed plants. Effect enhanced by low pH and surfactants. Transport rate 0–70 cm per hr.	15, 16
39	Bean Cotton Maize Millet Rice (*Oryza sativa*) Soybean (*Glycine max*) Other plants	Leaf Stem Root	2,4-D and other halogenated phenoxy-acetic acids	A, B	Application of labeled compound to one leaf and harvest of plant at intervals for C^{14} assay demonstrated that translocatability but not penetrability or metabolic inactivation was correlated with varietal susceptibility. Translocatability of phenoxyacetic acids in several dicots was 5–70 times greater than in monocots, with following decreasing order; 4-fluoro-; 2,4-difluoro-; 4-chloro-; 2,4-dichloro-; 2,4,5-trichloro-.	84

40	Bean Cotton Soybean Tomato	Leaf Stem	2,4-D, ammonium salt	A, B	Growth reduction as affected by application to individual leaves of various ages was used as an index of translocation. Maximum reduction achieved with application to apical leaves or stem. Apical movement only through dead stem segments.	80
41	Bean Four o'clock (*Mirabilis jalapa*) Maize Tomato	Leaf Stem Root	amitrol and 3-hydroxy-1,2,4-triazole	A, B	Radioassay and autoradiography of seedlings dissected 22–24 hr. after application of C^{14}-labeled compound to a central or basal leaf demonstrated translocation to be 10–60 times faster for amitrol than for the hydroxy analog. Old leaves exported the greatest amount of amitrol, and it accumulated throughout the plant, whereas hydroxy-triazole was translocated mainly to the apices and margins of young leaves.	58
42	Bean Maize	Leaf Stem	fungal metabolites	A^1, B^2	Application of filtrate of *Penicillium thomii* or *Arachniotus trisporus* culture to one leaf resulted in growth repression and abnormal development of sunsequent leaves.	22
43	Bean Maize	Leaf Stem	dalapon and 2,2,3-TPA[11]	A, B	By means of autoradiography and radioassay of plant parts after foliar application of C^{14}-labeled compounds, it was found that absorption was as complete after 2 hr. as after 7 days. Movement was predominantly toward rapidly developing tissues, and increasing the concentration decreased percentage transported. Similarity of absorption and translocation in sensitive (bean) plants and resistant (corn) plants suggests absorption and translocation are not involved in the selective toxicity.	50
44	Bean Maize Oats	Leaf Stem	2-iodo-3-nitrobenzoic acid	$A^{1,2}$,B^2	Activity of I^{131} determined in young leaves 8 days after application of the labeled compound to old leaves. Bean accumulated most, with activity concentrated in meristematic regions.	65
45	Bean Maize Oats Sunflower Wheat (*Triticum* sp.)	Leaf Stem Root	2,4-dichloro-5-iodophenoxy-acetic acid, morpholine salt	A, B	Determination of activity in various plant portions at different intervals after application of the I^{131}-labeled compound to one leaf. Activity in bean hypocotyl appeared 6 hr. after application. Movement out of maize leaves (also oats and wheat) was slower.	34
46	Bean Oats	Leaf Stem Root	2-iodo-4-chlorophe-noxyacetic acid	A, B	I^{131}-labeled material applied to one leaf and followed at various intervals by autoradiography. Movement throughout plant in 27 hr. (in the case of bean). Rate of transport 1.9–3.8 cm per hr. in bean; slower in oats.	25
47	Bean Sugarcane (*Saccharum officininarum*)	Leaf Stem	2,4-D	A^1,$B^{1,2}$	C^{14}-labeled 2,4-D applied to a lower leaf, and followed by subsequent formative effect and radioassay, was readily absorbed by both bean and sugarcane. However, about 10 times more C^{14} was translocated to the growing point of the bean than of the cane.	4
48	Bur-cucumber (*Sicyos angulatus*) Cocklebur (*Xanthium commune*) Jimsonweed (*Datura stramonium*)	Leaf Stem Root	2,4-D		Absorption and translocation was determined by radioassay after application of C^{14}-labeled 2,4-D to leaves or roots. Wide differences in susceptibility of the species could not be related to translocation, suggesting variable sensitivity to 2,4-D may be due to an internal metabolism peculiar to the species.	85

Entry No.	Plant name	Plant part	Substance	Translocation direction	Remarks	Reference No.
49	Canada thistle (*Cirsium arvense*) Johnsongrass (*Sorgum halepense*) Soybean	Leaf Stem Root	amitrol	A, B	Autoradiography and chromatography of plant parts after application of C^{14}–labeled compound to a leaf or leaf axil showed movement throughout plant in 30 hr. Metabolism rate of amitrol variable in different species, as determined by appearance of a labeled unknown.	76
50	Cocklebur (*Xanthium* sp.) Maize Peanut (*Arachis hypogaea*) Tomato Other plants	Leaf Stem Root	MH	A^{1},$B^{1,2}$	Repeated application to single leaf or by spraying resulted in translocation to regions of meristematic activity and formative effect thereto.	68
51	Cotton	Cotyledon Stem Root	2,4–D; amitrol; urea	B	Radioanalysis of culture solution a few days after application of C^{14}–labeled compounds to cotyledons showed only 2,4–D to be exuded from roots, although all compounds were translocated thereto in 2 hr. Because of absorption in tissue, distribution of 2,4–D in plants was less than that of other compounds.	13
52	Cotton	Leaf Stem	amitrol	A^{1}, B^{2}	Autoradiography of the plants at various intervals after application of C^{14}–labeled compound to basal leaves verified movement into the apical portion within 24 hr. Movement continued up to 7 days.	59
53	Cotton	Leaf Stem	amitrol	A, B	Apical or basal leaves were submerged in a solution of the substance. Injury appearing in nontreated leaves indicated bi-directional movement in the stem. but only acropetal movement could traverse a stem girdle.	35
54	Cotton Flax (*Linum* sp.) Milo (*Sorgum vulgare*) Rice Watermelon (*Citrullus vulgaris*) Other plants	Cotyledon Leaf Stem	MH	A, B	Application as a spray or only to cotyledons and stem resulted in translocation to meristematic regions as evidenced by stunting and development of abnormal leaves.	18
55	Hickory (*Carya tomentosa*) Privet (*Ligustrum vulgare*)	Leaf Stem	AMS[12]	A, B	Labeled material was applied to stem frill, the S^{35} being followed by autoradiography. Acropetal movement traversed a stem girdle, but basipetal movement did not. Rate of transport 0.6–2.5 cm per hr.	12
56	Johnsongrass Nutgrass (*Cyperus rotundus*)	Leaf Stem Rhizome	amitrol; dalapon; 2,2,3–TPA; 4–CPA[13]	A, B	Thirty days after foliage spray, rhizomes were separated and planted. Shoots arising therefrom were stunted and chlorotic. Translocation enhanced by addition of wetting agents. Rate of movement through horizontal rhizomes 0.03–0.05 cm per hr. Later studies on Johnsongrass showed dalapon and amitrol to be effectively transported, whereas other compounds were not. Low soil moisture decreased transport of 2,2,3–TPA, as did shading in the case of amitrol. These factors had little effect on movement of other compounds.	37 38

					little effect on movement of other compounds.	
57	Maize Oats	Leaf Stem Root	IPC[14]	A, B	About 1 percent or less of C^{14}–labeled compound applied to cut surface of oat leaf translocated to stem or root within 7 days. Absorption and movement from cut or intact root were even smaller. Transport nil in maize.	5
58	Maize Pea (*Pisum sativum*)	Leaf Stem Root	TCA[15], sodium salt	A, B	Outer half of the third leaf was dipped into a solution of the C^{14}–labeled substance. After 24 hr., activity measurements and autoradiograms indicated movement into roots and other leaves. No apparent metabolism to other products.	8
59	Maize Wheat	Leaf Stem Root	2,4–D	A, B	One to four days after application of C^{14}–labeled 2,4–D to an older leaf, 2,4–D and 3 metabolic products thereof were recovered throughout the plants. Determination by radiochromatography. Most activity in young leaves, some in stem and sheath, and least in roots.	28
60	Marabu (*Dichrostachys nutans*)	Stem	2,4–D, butoxy–ethanol ester	A, B	Positive recovery (determined by bioassay) 19 cm from top of 2-ft sucker, 6 hr. after apical application. Negative recovery after 30 hr. suggests rapid transport and/or metabolism. Transport also shown by effect on basal buds, which were inhibited in sprouting even when shoot excised 6 hr. after application. Acropetal transport occurred through stem girdle. Basipetal did not, and was therefore extraxylary.	41
61	Marabu	Shoot	2,4,5–T, butoxy–ethanol ester	A, principally	2,4,5–T, applied in oil or water at different levels on the surface of the shoot, was translocated in an acropetal direction as evidenced by bioassay of tissues and ultimate death of leaves and stems above the treated area. Slight basipetal movement did occur with bark application however, as indicated by inhibition of basal sprouting.	40
62	Mesquite (*Prosopis juliflora*)	Leaf	2,4,5–T, various formulations	A^{1},$B^{1,3}$	Maximum translocation out of branch tips 50–90 days after leaf emergence in spring, when root sugars are undergoing rapid buildup. Little translocation if total root sugars decreasing and reducing sugars abundant. Anatomical studies showed phloem proliferation and resultant transport inhibition could occur from too high concentration of either 2,4,5–T or surfactant.	33, 46
63	Mesquite	Leaf Stem Root	2,4–dichloro–5–iodophenoxy–acetic acid	B	Four days after spraying the upper half of plant with solution of I^{131}–labeled compound, activity was determined in more basal tissue. The use of emulsifying agent increased proportion of activity in root and hypocotyl over that in stem, but less than 3 percent moved out of the treated foliage.	7
64	Mesquite	Leaf Stem	2,5–D[16], butoxy–ethoxypropanol ester; 3,4–D[17], butoxy–ethanol ester; dalapon, sodium salt	A, B	Apical epinasty and injury to young leaves as well as injury to basal leaves were determined at intervals after application to central leaves. Acropetal movement more intense than basipetal.	45
65	Nutgrass	Leaf Stem Root Tuber	2,4–D; 2,4,5–T; amitrol; MH	$A^{1,3}B^{1,3}$	Transport determined by autoradiography after application to single leaf. Amitrol reached root tip in 2 hr.; 2,4–D and 2,4,5–T were slower. No movement out of treated leaf kept in dark. Rate of transport 20–25 cm per hr.	1

Entry No.	Plant name	Plant part	Substance	Translocation direction	Remarks	Reference No.
66	Oak (*Quercus douglasii* *Q. wislizenii*) Ceanothus (*Ceanothus cuneatus*) Coyote brush (*Baccharis pilularis*) Manzanita (*Arctostaphylos manzanita*) Toyon (*Photinia arbutifolia*) Willow (*Salix lasiolepis*)	Leaf Stem	2,4–D and urea	A^1,$B^{1,2}$	Autoradiography of bark samples collected 1–21 days after treatment of single leaf with C^{14}–labeled compound, at distances up to 150 cm from leaf. Acropetal transport less pronounced than basipetal and dependent upon season and plant species. Transport active many months in evergreen species, but only short period in deciduous. Contact injury inhibited and soil moisture enhanced translocation.	52
67	Pea Tomato	Leaf Stem Root	2,4–D	A^1, $B^{1,2}$	Basipetal movement more extensive than acropetal, as determined by radioassay at various intervals after application of C^{14}–labeled compound to lower leaf. One of two active metabolic products of 2,4–D was more common in pea and the other in tomato.	27
68	Soybean	Leaf Stem Root	2,4–D, sodium salt (Also P^{32})	A^1, B^2	Transport, determined by growth repression after severing a basal leaf at various intervals after application thereto, was reduced by low leaf carbohydrate content. Temperature coefficient for transport of 2,4–D and P^{32} (determined by autoradiography) showed Q^{10} values of about 2.	6
69	Spider flower, giant (*Cleome spinosa*) Tomato	Stem	2,4–D; 3–indole–acetic acid; indole-butyric acid; naphthaleneacetic acid	A,B	Application was made to the stem in the form of a ring. Translocation determined by degree of rooting of cuttings taken above or below application point. Transport in both directions across a stem girdle indicated principal movement to be in xylem.	32
70	Strawberry (*Fragaria* sp.)	Leaf Runner	MH, diethanolamine salt	B^2	Activity detected (by autoradiography) in runner tips 30 hr. after application of C^{14}–labeled compound to mature leaf. It could move through several crowns to concentrate in a runner tip, but did not move against growth gradient back toward formed crown or plant.	9

71	Sugarcane	Leaf Stalk Root	2,4–D	A, B	Radioassay after application of C^{14}–labeled 2,4–D to a single leaf showed very little translocation into growing tips of shoot and root, and young leaves, as compared with bean.	10
72	Tobacco (*Nicotiana* sp.)	Stem	MH	B	Application to cut surface after topping resulted in basipetal transport as determined by inhibition of adventitious buds and increased formation of carbohydrates in leaves developing after treatment.	2
73	Tomato	Leaf Stem Root	2,4–D	B	Potassium-deficient plants given potassium via roots 3 days before or simultaneously with 2,4–D application to one leaflet showed greater transport than plants given potassium 24 hr. after 2,4–D, as evidenced by growth repression, formative effect, and autoradiography.	75
74	Tomato	Leaf Stem Root	2,4–D, sodium salt	A, B	Movement throughout plant determined (photometric chemical analysis) 24–48 hr. after application to second basal leaf or to soil.	24
75	Tomato	Leaf Stem Root	2,4–D	A[1], B[1,2]	C^{14}–labeled 2,4–D applied to first true leaf of phosphorus-deficient plants. Translocation out of leaf determined by stem curvature and autoradiography. Addition of phosphorus to the nutrient 8 hr. or 3 days before 2,4–D application enhanced its translocation, particularly with with the 3-day pretreatment.	77
76	Tomato	Leaf	monuron	A, B	Application of the C^{14}–ring–labeled compound was made to a terminal leaflet, subsequent movement being followed by autoradiogram. Very little basipetal movement in the leaves. Acropetal movement only when given via root system, probably in xylem.	36
77	Velvetbean, Florida (*Stizolobium deeringianum*)	Leaf Stem	monuron	A	Short mid-stem sections (intact plants) were immersed in a solution of the substance several days. Only leaves acropetal to treated sections showed typical injury after 6 days.	67

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Weed Control Practices, Labor Requirements and Costs in Cotton Production

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The cotton-producing industry today faces a real challenge in its attempt to control weeds in cotton. It is a problem with many facets. Differences in weed species, topography, soil type, scale of operation, rainfall, and many other factors make it difficult to develop single practices that work satisfactorily across large areas of the Cotton Belt.

In many areas, cotton production is completely mechanized for all operations except weed control. Mechanization has brought the weed-control problem into sharp focus. For example, in the Yazoo-Mississippi Delta, hand labor for weed control accounts for 60 to 70 percent of the total labor required to produce cotton under mechanized conditions (4).

The direct costs of controlling weeds in cotton have been estimated by several workers in the Mid-South. Porter et al. (7) reported in 1951 that of various combinations of a pre-emergence herbicide, herbicidal oil, and flame, a combination of post-emergence herbicidal oil and flame gave the best cost-labor balance. The addition of the pre-emergence herbicide to the best practice added very little to the cost or the performance of the weed-control system. Crowe and Holstun (4) in 1953 reported that weed control with post-emergence oils alone or in combination with pre-emergence herbicides was slightly more expensive than with control by cross-cultivation. These authors discussed some of the hazards of the pre-emergence herbicides then in use and pointed out the difficulty of proper application of herbicidal oil on a practical basis. In 1956 McWhorter et al. (6) concluded that pre- or post-emergence herbicides or cross-cultivation materially reduced the labor required for weed control. The cost was reduced in some situations as compared with hand hoeing, but not in others. Various combinations of herbicides with or without cross-cultivation were more effective in reducing labor requirements, but did not necessarily result in the lowest costs as compared with those of uncombined practices. Porter et al. (8) concluded in 1957 that certain pre-emergence herbicides tended to stabilize the cost of weed control in cotton, and that their use had resulted in an average increase in profits. These workers pointed out, however, that the use of pre-emergence herbicides may cost more than hand hoeing where weed infestations are low. Other workers have reported similar results. From these studies, it can be seen that there are at least four basic

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methods besides conventional cultivation and hand hoeing that can be used to control weeds in cotton. These are the use of a pre-emergence herbicide, a post-emergence herbicidal oil, flame, and cross-cultivation. Weed control with residual-type post-emergence herbicides (1, 2, 5) would be comparable in some ways with control from either post-emergence oils or flame.

Pre-season selection of the most economical weed-control practice for a particular field in any given year is impossible at present. However, with certain information and some reasonably accurate estimates, a farm operator should be able to select in advance the system that will give him the greatest return over a period of several years.

Information and estimates that need to be known are:

1. Soil type and topography.
2. Weeds present, including species, general level of infestation, and usual time of appearance in field.
3. Current costs of weed control with conventional methods, and the proportion of these costs spent because of weeds that can be controlled by newer methods.
4. Basic costs (costs that are more or less fixed and that vary only slightly from year to year) of the various weed-control practices.
5. Relative effectiveness of each practice in reducing hoe labor.
6. An accurate evaluation of the operator's ability to carry out any or all phases of the newer practices.
7. A clear understanding of what the operator wishes to accomplish in terms of a balance between reduction of labor, costs, and certainty of success in weed control.

The study reported herein was initiated in 1956 to provide some of this information in relation to the four weed-control practices listed previously.

MATERIALS AND METHODS

A 16-treatment experiment involving the use of a pre-emergence herbicide, post-emergence applications of herbicidal oil, and flame on hill-dropped and cross-cultivated cotton in all combinations was conducted. A split-split plot design in randomized complete blocks with three replicates was used. Flame treatments were applied to sub-sub plots, pre-emergence treatment and post-emergence oil treatment were applied to sub plots, and main plots were used for the comparison of hill-dropping with cross-cultivation. Minimum sub-sub plot size was four 40-inch rows 60 feet long. The test was repeated in different fields and years until a wide range of weed infestations had been sampled. To obtain this range, three plantings were made in 1956, two in 1957, and one in 1958. Since the purpose of this report is to present performance data under a range of conditions, two of these plantings were omitted as they were essentially duplicated by some of the others. All plantings were made on the Delta Branch, Mississippi Agricultural Experiment Station, Stoneville.

All measurements of costs of machinery were based on performance

rates of 4-row equipment. The hill-dropped plots were planted at the rate of 17 lb/A of machine-delinted seed with hill spacings of 14 to 23 inches. Seed in the cross-cultivated plots were drilled at rates of 60 to 75 lb/A. Cotton seedlings in the cross-cultivated plots were automatically thinned in the process of cultivating with and at right angles to the rows. In computation of costs, however, assumed rates of 25 and 75 lb/A of seed were used for hill-dropping and cross-cultivation, respectively, as these rates are more in line with current farm practices. Insects were controlled by conventional methods. All equipment used is currently available for 4-row tractors. Most of the plot operations were carried out with conventional 2-row equipment, but in some instances 1-row equipment was used to cultivate check plots. Hoe-labor costs were computed on the basis that a transient labor force of 25 active hoe hands, one crew leader, and one hoe filer was used for all practices. The crew leader and hoe filer, who normally do not hoe, were paid at the regular rate for hoe hands. For this experiment, a rate of $12.50/day was charged for labor transportation. Thus for hoe labor, which is quoted at $0.35/hr, the actual cost to the farm operator is $0.43/hr. At a quoted price of $0.60/hr, the actual cost is $0.70/hr.

All plots were regularly inspected with regard to determining the need for the various weed control operations. Generally the recommendations of Bingham et al. (3) were rigidly adhered to with respect to timing and method of seedbed preparation, planting, cultivation, herbicide application, and other operations. The initial applications of herbicidal oil, however, were made as soon as possible after the cotton reached a height of 2 rather than 3 inches. Shielded cultivation (with equipment designed to avoid movement of soil onto the treated drill area) was used on the chemically treated plots so long as the drill area remained essentially free of weeds, and on those plots which were to receive post-emergence oil. Unshielded cultivation was normally used on the check plots, and on chemically treated plots after weeds appeared in the drill area provided the plot treatment did not require future application of herbicidal oil. This deviates from the cited recommendations only in that unshielded cultivation was sometimes used in plots that were flamed at a later date. The timeliness with which mechanical operations and hoeing were carried out in this experiment is believed to be comparable to that normally expected in a well-organized farming operation. Further, it is a considered opinion that none of the operations were beyond the ability of the average farm operator. It is believed, however, that most farm operators would be unwilling to take the necessary steps to use herbicidal oils properly. A few farm operators would consider the use of flame too complicated to be practical.

In determining hoe-labor requirements the same hoe crew was used for all treatments within a replication. If inspection of a plot indicated that it did not need hoeing, it was not entered by the hoe crew, and the hoe time, for that date was recorded as zero. Plots were not hoed, if in the opinion of the investigators, the weed infestation could be removed at a later date without excessive risk of damage

to yield or of a large increase in the amount of labor required for removal. Situations meeting this requirement usually involved a light infestation with single weeds spaced at long intervals of distance. Hoeing of a plot was started by a signal and all members of the crew hoed steadily until the entire plot was finished. The operation was timed with a stop watch. The hoe crew was trained to hoe as rapidly as the weed infestation would permit, but not faster than a pace which could be maintained throughout the day.

Weeds present included *Amaranthus* spp. (pigweed), *Brachiaria* spp. (brachiaria), *Ipomoea purpurea* (L.) Roth (morning-glory), *Digitaria sanguinalis* (L.) Scop. (crabgrass), and other similar annuals. Perennials present as spot infestations were controlled by hoeing without charge to any treatment. Weed infestations encountered may be summarized as follows. In the first planting, there was a moderate early-season infestation and the late-season infestation was light (early season includes that part up through the last safe application of herbicidal oil). In the second planting, infestations were light in both parts of the season. In the third planting, there was a heavy early-season infestation and there was a moderate late-season infestation. Infestation in the fourth planting was moderate in the early season and heavy in the late season. Planting numbers given here exclude those numbers assigned to plantings not being reported.

The pre-emergence herbicide used was isopropyl *N*-(3-chlorophenyl)carbamate (CIPC) at the broadcast rate of 8 lb/A applied only to a 12-inch band centered on the drill. The cost assigned to it, however, was based on that of a comparable rate (1 lb/A broadcast–.3 lb/A band) of 3-(3,4-dichlorophenyl)-1,1-dimethylurea (diuron), which is considerably cheaper at present. Ample data are available to justify this substitution. The assumption was made that 25 percent of all cotton planted must be replanted for one reason or another. In such instances seed and pre-emergence herbicides are lost. To compensate for this loss, 1.25 times the cost/A/application was charged for the pre-emergence herbicide and for extra seed required for cross-cultivation. The post-emergence oils recommended by Bingham et al. (3) were used at band rates of 5 and 7 gal/A with about one fourth of the row width being treated.

It should be emphasized that this study was conducted to evaluate practices rather than chemicals. It is believed that the data obtained will be applicable to some extent to other herbicides that may be developed for use in these four basic methods. For instance, if a residual lay-by herbicide is discovered to be more effective than flame on late-season weeds, it would seem safe to assume that only an evaluation of its late-season performance would be necessary to predict its effectiveness in combinations in which it displaced flame.

Results and Discussion

To simplify the discussion of the results, cultivation and hand hoeing as needed, the only methods of weed control used on the check plots, are considered as primary to each weed-control practice. Pre- and post-emergence herbicides, flame, and cross-cultivation are

considered as extra components that may be added to the primary ones. For instance, cultivation, hoeing, and a pre-emergence herbicide on hill-dropped cotton would be a one-component practice (one component in addition to the primary practice).

In the strictest sense, the results of the study reported here should be applied only to relatively large, well-drained fields of sandy loam to silt loam soils in the Yazoo-Mississippi Delta, in which the primary weed problem consists of annual weeds. Some implications of the data should, however, be of value in other situations provided allowances are made for the differences.

The discussion of this study is based on the assumption that none of the treatments had positive or negative effects on yield. This and other studies have indicated that the recommended use of pre-emergence herbicides, post-emergence oils, cross-cultivation, and flame do not decrease yields as measured by longtime averages.

Seasonal labor considerations. It is possible that at this stage the real benefits that accrue to the new practices in weed control do not lie in the direction of reducing costs. But they may have far-reaching effects on the future of the cotton enterprise. By keeping hand-labor units at very low levels and allowing for a better distribution of these labor requirements throughout the production season, production risks, so far as weed control is concerned, are held to a minimum. If requirements for hoe labor can be held to levels low enough to be met by members of the families of year-round plantation workers, and indications are that they can be, it will no longer be necessary to maintain a labor reserve. This is the step that would shift cotton production from a labor-intensive to a labor-extensive enterprise and permit a working family to produce not from the traditional 10 acres, but perhaps from 10 times that acreage.

In the two seasons that involved only light or moderate weed infestations, use of pre- or a post-emergence herbicide or cross-cultivation was adequate, and all were about equally effective in reducing hoe-labor requirements (Table 1).

With heavy early-season and moderate late-season weed infestations, hoe-labor requirements for all of the single-component practices rose to unsatisfactory levels. Except for flame combined with cross-cultivation, all two-, three-, and four-component practices held total hoe-labor requirements to less than 20 hr/A for this particular type of season.

With moderate early-season and heavy late-season infestations the practices outstanding in reducing hoe-labor requirements were the two-, three-, and four-component practices which contained both flame and herbicides. The combinations of cross-cultivation with the pre-emergence herbicide, post-emergence oil, or with both, held hoe-labor requirements to reasonable levels, but these three practices were inferior to any two-component practice involving flame except the use of cross-cultivation and flame. Flame alone, on either hill-dropped or cross-cultivated cotton, was ineffective because it did not control early-season weeds.

Table 1. Average effect of various weed-control practices on hoe-labor requirements in cotton in seasons with various levels of weed infestation (3 replications), Stoneville, Mississippi.

Method of planting, cultivation, and weed control in drill area in addition to hoeing	Hours of hoe-labor per acre for cotton planted:			
	5/4/56[a]	4/18/56[b]	5/18/57[c]	5/9/58[d]
Hill-drop+conventional cultivation:				
None	14	23	48	53
Flame	13	20	37	42
Pre-emergence herbicide	7	9	21	35
Pre-em. herb. +flame	6	6	14	6
Post-em. herb	7	10	24	30
Post-em. herb. +flame	6	7	15	6
Pre-+post-em. herb	3	5	16	27
Pre-+post-em. herb. +flame	2	2	11	5
Drill+cross cultivation:				
None	6	9	29	28
Flame	5	8	21	23
Pre-em. herb	3	3	16	18
Pre-em. herb. +flame	2	2	10	2
Post-em. herb	5	5	13	15
Post-em. herb. +flame	4	4	10	2
Pre-+post-em. herb	2	2	12	14
Pre-+post-em. herb. +flame	1	2	8	2

[a]Light early-season and light late-season weed infestations.
[b]Moderate early-season; light late-season weed infestations.
[c]Heavy early-season and moderate late-season weed infestations.
[d]Moderate early-season and heavy late-season weed infestations.

The effects on hoe-labor requirements do not show all the weed-control effectiveness of the various treatments. At least two other factors, one of which was measured in this study, should be pointed out. In the last two plantings, the cross-cultivated plots tended to be somewhat weedier at harvest time than their counterparts in the hill-dropped cotton. This increase in weeds is believed to be result of the wider hill-spacing in the cross-cultivated plots, which reduced the shading effect of the cotton on late-appearing weeds. The second factor, which was not measured in this study, was that many weeds killed by late flamings would not have been controlled without flame. Repeated control of these late-season weeds over a period of several years should tend to decrease the weed population of the field as compared with practices that allow late-appearing weeds to produce seed.

Relative costs of the different weed-control practices. The costs of these 16 weed-control practices are more difficult to evaluate than their effect on hoe-labor requirements. In this report the cost of a weed-control practice refers only to direct costs which include expenditures for equipment, materials, extra seed, and labor necessary primarily because of the presence of weeds. Not included in this study are evaluations of hidden or indirect costs of weed control such as reduction in grade of lint because of grass, utilization of production resources needed for other crops, and maintaining large labor pools. These indirect costs, although difficult to measure,

should receive consideration in specific cases of selection of a practice to be used.

Cost data for this experiment are presented in Tables 2 to 4. While the data in all three tables are interrelated, each table serves a purpose not included in the others. The data of Table 2 indicate what have been labeled the basic costs of the various weed control

Table 2. Basic costs of various weed-control practices in cotton (all specified costs minus hoe-labor costs) in seasons with various levels of weed infestation, Stoneville, Mississippi.

Method of planting, cultivation, and weed control in drill area in addition to hoeing	Basic cost, dollars per acre, of weed-control practices[a] for cotton planted:			
	5/4/56[b]	4/18/56[c]	5/18/57[d]	5/9/58[e]
Hill-drop +conventional cultivation:				
None	2.50	2.50	4.50	3.50
Flame	4.40	4.40	9.55	7.30
Pre-emergence herbicide	5.45	5.45	7.45	6.95
Pre-em. herb. +flame	7.35	7.35	12.50	10.75
Post-em. herb	5.90	5.90	7.40	8.35
Post-em. herb. +flame	7.80	7.80	12.45	12.15
Pre- +post-em. herb	8.85	8.85	10.35	9.35
Pre- +post-em. herb. +flame	10.75	10.75	15.40	13.15
Drill +cross cultivation:				
None	7.40	7.40	8.90	8.40
Flame	9.30	9.30	13.95	12.20
Pre-em. herb	10.35	10.35	11.85	11.35
Pre-em. herb. +flame	12.25	12.25	16.90	15.15
Post-em. herb	9.35	9.35	11.80	11.80
Post-em. herb. +flame	11.25	11.25	16.85	15.60
Pre- +post-em. herb	12.30	12.30	14.75	12.80
Pre- +post-em. herb. +flame	14.20	14.20	19.80	16.60

[a]Computed as follows (figures include labor, materials, machinery):

1. Additional seed for cross-cultivated cotton—	$3.90/A
2. Pre-emergence herbicide and its application—	$2.95/A
3. Post-emergence oil, its application at 7 gal/A, plus cultivation—	$2.45/A/application
4. Post-emergence oil, its application at 5 gal/A, plus cultivation—	$1.95/A/application
5. Flame and cultivation—	$1.45/A/application
6. Flame without cultivation—	$1.25/A/application
7. Cultivation or cross-cultivation—	$0.50/A/application

[b]Light early-season and light late-season weed infestations.
[c]Moderate early-season; light late-season weed infestations.
[d]Heavy early-season and moderate late-season weed infestations.
[e]Moderate early-season and heavy late-season weed infestations.

practices. These data are simply the total costs minus the cost of hoe labor. They represent the costs of labor (except hoe labor), equipment, and materials associated with each practice. The experimental inference is that these figures represent the theoretical minimum cost of each of the 16 practices for each level of weed infestation encountered in the study. The variation in basic costs from one year to another is the result of differences in the number of applications of post-emergence oil, cultivation, and flame. As compared with the cost of hoe labor these basic costs tend to rise only slightly as the weed infestation increases, because the cost of hoe labor is determined primarily by the degree of weed infestation while the cost of other operations is usually limited by a number of factors other than

Table 3. Average effect of various weed-control practices on the cost of controlling weeds in cotton in seasons with various levels of weed infestation and with hoe labor computed at a rate of $0.43/hr (3 replications), Stoneville, Mississippi.

Method of planting, cultivation, and weed control in drill area in addition to hoeing	Total cost, dollars per acre, of weed control[a] for cotton planted:			
	5/4/56[b]	4/18/56[c]	5/18/57[d]	5/9/58[e]
Hill-drop +conventional cultivation:				
None	8.52	12.39	25.14	26.29
Flame	9.99	13.00	25.46	25.36
Pre-emergence herbicide	8.46	9.32	16.48	22.00
Pre-em. herb. +flame	9.93	9.93	18.52	13.33
Post-em. herb	8.91	10.20	17.72	21.25
Post-em. herb. +flame	10.38	10.81	18.90	14.73
Pre- +post-em. herb	10.14	11.00	17.23	20.96
Pre- +post-em. herb. +flame	11.61	11.61	20.13	15.30
Drill +cross cultivation:				
None	9.98	11.27	21.37	20.44
Flame	11.45	12.74	22.98	22.09
Pre-em. herb	11.64	11.64	18.73	19.09
Pre-em. herb. +flame	13.11	13.11	21.20	16.01
Post-em. herb	11.50	11.50	17.39	18.25
Post-em. herb. +flame	12.97	12.97	21.15	16.46
Pre- +post-em. herb	13.16	13.16	19.91	18.82
Pre- +post-em. herb. +flame	14.63	15.06	23.24	17.46

[a]See Table 2.
[b]Light early-season and light late-season weed infestations.
[c]Moderate early-season; light late-season weed infestations.
[d]Heavy early-season and moderate late-season weed infestations.
[e]Moderate early-season and heavy late-season weed infestations.

degree of weed infestation. For instance, even in severe weed infestations, no more than three applications of herbicidal oil would be made because of the possibility of injury to the cotton. Likewise the danger of damaging large, lodged cotton would prevent the application of additional flame or cross-cultivation. The cost of buying and applying the pre-emergence herbicide is, of course, fixed prior to the development of any weed infestation.

In order to obtain a financial advantage with one of the newer practices over the check practice of hoeing hill-dropped cotton, one condition must prevail. The monetary value of the hoe-labor reduction obtained by using the new practice must exceed the difference in the basic cost of the two practices. The monetary value of this hoe-labor reduction is determined by the magnitude of the reduction and the wage rate. The data of Table 3 were computed by adding the basic cost data from Table 2 to the product of hoe-labor requirements (Table 1) and the prevailing wage rate of $0.43/hr for each practice. These data indicate the relative positions in relation to total cost for the various practices at each level of weed infestation. Combined with the data of Tables 1 and 2 they indicate the shift of importance from basic costs to efficiency of performance as the weed infestations increase. The effects of an increase in the wage rate for hoe labor on total costs are indicated by the data of Table 4, which are identical to those of Table 3 except that the wage rate used was

Table 4. Average effect of various weed-control practices on the cost of controlling weeds in cotton in seasons with various levels of weed infestation and with hoe labor computed at a rate of $0.70/hr (3 replications), Stoneville, Mississippi.

Method of planting, cultivation, and weed control in drill area in addition to hoeing	Total cost, dollars per acre, of weed control[a] for cotton planted:			
	5/4/56[b]	4/18/56[c]	5/18/57[d]	5/9/58[e]
Hill-drop +conventional cultivation:				
None	12.30	18.60	38.10	40.60
Flame	13.50	18.40	35.45	36.70
Pre-emergence herbicide	10.35	11.75	22.15	31.45
Pre-em. herb. +flame	11.55	11.55	22.30	14.95
Post-em. herb.	10.80	12.90	24.20	29.35
Post-em. herb. +flame	12.00	12.70	22.95	16.35
Pre- +post-em. herb.	10.95	12.35	21.55	28.25
Pre- +post-em. herb. +flame	12.15	12.15	23.10	16.65
Drill +cross cultivation:				
None	11.60	13.70	29.20	28.00
Flame	12.80	14.90	28.65	28.30
Pre-em. herb.	12.45	12.45	23.05	23.95
Pre-em. herb. +flame	13.65	13.65	23.90	16.55
Post-em. herb.	12.85	12.85	20.90	22.30
Post-em. herb. +flame	14.75	14.05	23.85	17.00
Pre- +post-em. herb.	13.70	13.70	23.15	22.60
Pre- +post-em. herb. +flame	14.90	15.60	25.40	18.00

[a]See Table 2.
[b]Light early-season and light late-season weed infestations.
[c]Moderate early-season; light late-season weed infestations.
[d]Heavy early-season and moderate late-season weed infestations.
[e]Moderate early-season and heavy late-season weed infestations.

$0.70/hr rather than $0.43/hr. The primary effect of the higher rate is that the performance of a practice in reducing hoe-labor becomes more important in fixing total cost, while basic cost becomes less important, than with the lower wage rate.

In general the pre- or the post-emergence herbicide afforded economical control of early-season weeds, but fell short in control of late-season weeds. Flame, not being applied in the early-season, was effective only against late-season weeds. Cross-cultivation appeared to be less effective than chemicals for early-season control and less effective than flame for late-season control, but had the advantage of providing substantial control in both early- and late-season phases.

Combined consideration of labor and cost. Of the practices evaluated it is relatively easy to visualize that any one of the 15 one-, two-, three-, or four-component practices would have many advantages over the practice of hoeing and cultivating hill-dropped cotton. Selection within these 15 possible practices is more difficult, for any one could conceivably be better than the others for a particular situation. Whereas the data of Tables 1 to 4 are of value in evaluating the performance of the 16 weed-control practices, Table 5 may be of more practical value. These data represent the maximum total costs and maximum hoe-labor requirements of each treatment without regard to the planting in which it occurred. The operation of many cotton farms is financed on a short time basis, and therefore

Table 5. Average minimum performance[a] produced in 4 plantings of cotton by various weed-control practices (3 replications), Stoneville, Mississippi.

Method of planting, cultivation, and weed control in drill area in addition to hoeing	Highest total cost dol/A with wage rate at:		Greatest hoe-labor requirements hr/A		
	$0.43/hr	$0.70/hr	For first month after planting	For any one hoeing	For any season
Hill-drop +conventional cultivation:					
None	26	41	24	37	53
Flame	25	37	24	26	42
Pre-emergence herbicide	22	31	5	30	35
Pre-em. herb. +flame	19	22	5	7	14
Post-em. herb.	21	29	3	24	30
Post-em. herb. +flame	19	23	3	8	15
Pre- +post-em. herb.	21	28	0	22	27
Pre- +post-em. herb. +flame	20	23	0	5	11
Drill +cross cultivation:					
None	21	29	9	20	29
Flame	23	29	9	15	23
Pre-em. herb.	19	24	0	18	18
Pre-em. herb. +flame	21	24	0	4	10
Post-em. herb.	18	22	3	15	15
Post-em. herb. +flame	20	24	3	5	10
Pre- +post-em. herb.	20	23	0	14	14
Pre- +post-em. herb. +flame	23	25	0	4	8

[a]The data within any practice are not necessarily from the same planting.

a practice that performs well under adverse conditions may be of more practical value than a practice that is actually better over a long period of time, but tends to fail completely in seasons of adverse conditions.

Hazards of high total costs, regardless of wage level, appeared to be present on a relative basis for the practices used on the flamed and unflamed checks and the four-component practice. At a wage rate of $0.70/hr, all other one-component practices, the pre- and post-emergence treatment combination on hill-dropped cotton and flame on cross-cultivated cotton should be added to this list of practices with hazards of high costs.

The pre- or the post-emergence treatment alone or in any combination afforded almost complete protection against excessive hoe-labor requirements during the stand-establishment phase of the growing season. Cross-cultivation was almost as effective. Flame cannot be used this early in the season.

No single-component practice afforded adequate protection against the occurrence of at least one heavy hoeing during the season. Only two-, three-, and four-component practices containing the flame component afforded this protection.

No single-component practice held total labor requirements to 20 hr/A in all plantings. All three- and four-component practices did afford this protection as did all two-component practices except the use of the pre- and post-emergence treatment combination on hill-dropped cotton and flaming combined with cross-cultivation.

Of the methods of control studied, only one has appeared to be generally impractical on a farm basis although each of the others would be impractical in many situations. The use of post-emergence oils has been tried and discarded as too difficult by many farmers in the Mid-South. All of the other practices have been accepted and put into rather general use.

No attempt is made in this report to discuss the details of selection of a particular method or combination of methods for any specific problem. However, the data presented should be of value in this respect and the implications of the data for this purpose are reasonably self-evident.

Variability of the data. Summary data on main effects are presented in Table 6 to provide some indication of the variability of the data. Within plantings the primary source of variation was from deviations in hoe-labor requirements. Within sub-sub plot treatments within plantings, there was no variation in numbers of weed-control

Table 6. Summarized effects of various methods of weed control on hoe-labor requirements with two indications of variability of the data (3 replications), Stoneville, Mississippi.

Method of control (main effects) and variability indicators	Position in experimental design	Hoe-labor requirements, hours per acre for cotton planted:			
		5/4/56	4/18/56	5/18/57	5/9/58
Conventional cultivation[a]	Main plot	7.3	10.3	23.1	25.5
Cross-cultivated	Main plot	3.7	4.3	14.9	13.0
LSD at .05 level[b]		NS	2.8	NS	2.9
Coef. of var		75%	32%	42%	12%
Check	Sub plot	9.6	15.0	33.6	36.6
Pre-emergence herbicide	Sub plot	4.6	5.2	15.3	15.1
Post-em. herb	Sub plot	5.8	6.3	15.4	13.5
Pre- and post-em. herb	Sub plot	2.1	2.6	11.6	11.7
LSD at .05 level[b]		1.2	1.6	1.9	2.6
Coef. of var		25%	25%	11%	15%
No flame	Sub-sub plot	6.0	8.3	22.1	27.6
Flame	Sub-sub plot	5.0	6.3	15.8	10.9
LSD at .05 level[b]		0.4	0.5	0.1	1.2
Coef. of var		12%	12%	7%	10%

[a]Conventional-cultivation plots were hill-dropped to a stand and cross-cultivated plots were drilled.
[b]LSD figures presented only as an indication of the residual experimental error; significance of most interactions limits their value for differentiating main effects.

operations. There were minor variations between treatments within plantings in number of cultivations and post-emergence oil applications. The number of weed-control operations varied between plantings, but the variations are reflected in the basic cost data (Table 2).

Analyses of variance were made on hoe labor requirements by plantings, but no attempt was made to combine plantings since the weed-infestation levels were selected rather than random samples. All first-order interactions between main plot, sub plot, and sub-sub plot treatments were highly significant in at least two plantings.

There was no evidence of significance for the second-order interaction. Failure of the cross-cultivation main effect to reduce hoe labor significantly in two of the plantings is, with little doubt, due to the low degree of replication of main plots in the design combined with the effects of certain first-order interactions.

SUMMARY

Sixteen weed-control practices, involving combinations of hand hoeing, a pre-emergence herbicide, post-emergence oil, and flame in hill-dropped and cross-cultivated cotton, were evaluated for weed-control effectiveness in field plots at Stoneville, Mississippi.

The direct cost of controlling annual weeds by hoe labor and cultivation ranged from $8 to $26/A at the prevailing wage rate. Requirements for hoe labor ranged from 14 to 53 hr/A.

The data indicated that through the judicious use of a pre-emergence herbicide, post-emergence oil applications, flaming, and cross-cultivation, either singly or in various combinations, hoe labor requirements can be greatly reduced with appreciable savings in costs. With some combinations hoe labor was practically eliminated, but it appeared that simpler combinations producing less complete labor reductions may result in greater average profits because of the high basic cost of the most effective weed-control practices.

It was pointed out that all the new methods of weed control have limitations and that in some instances it may be impractical to use all or even any of the newer methods.

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Absorption and Translocation of 2,4–D in Several Annual Broadleaved Weeds[1]

M. Coburn Williams,[2] F. W. Slife,[3] and J. B. Hanson[3]

The outstanding success of 2,4-D as a selective herbicide stems from the great susceptibility of many broadleaved (dicotyledonous) weeds to the compound. Applications of 2,4-D which will eliminate many dicots will leave most grass crops relatively unaffected. Several suggestions that have been made for the differences in susceptibility between grasses and broadleaved weeds, including differences in foliar absorption (1), restricted translocation of the compound in grasses (3), and differences in detoxification of the 2,4-D molecule (2).

Not all broadleaved weeds are equally susceptible to 2,4-D, however. Some, such as bur cucumber (*Sicyos angulatus*) and jimson weed (*Datura stramonium*) are quite resistant and generally survive moderate 2,4-D applications. No experimental inquiries appear to have been made into the nature of the resistance of these dicot weeds to 2,4-D sprays. Presumably they might fail to absorb or translocate lethal amounts of herbicide; again, there may exist some internal cytoplasmic resistance, such as metabolic breakdown of the 2,4-D (4,5,10) or a reduced affinity of the molecule for the cytoplasmic sites of action. The experiments described here were conducted to evaluate the nature of 2,4-D resistance in selected broadleaved weeds.

Materials and Methods

Four dicotylendonous weeds known from field observations to possess widely different sensitivity to 2,4-D were selected as experimental material, and seed was collected in the field. In order of decreasing sensitivity these weeds are (1) cocklebur, *Xanthium commune;* (2) smartweed, *Polygonum pennsylvanicum;* (3) jimson weed, *Datura stramonium;* and (4) bur cucumber, *Sicyos angulatus.* Smartweed was not used in later experiments because of the difficulties encountered in breaking dormancy in the seed.

The following phases of absorption, translocation, and metabolism were studied: (1) relative sensitivity of the weed species to spray and nutrient solution applications of 2,4-D (2) absorption of radioactive 2,4-D by leaf and stem sections, (3) absorption and translocation of radioactive 2,4-D by growing plants, (4) evolution of $C^{14}O_2$ from 2,4-D-2-C^{14} and 2,4-D-1-C^{14} sidechain catabolism, and (5) transmission of 2,4-D between branches and across grafts.

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Relative sensitivity of weed species to spray and nutrient solution applications of 2,4-D.

Seeds were germinated in sand. Thirty seedlings of each species were transplanted into individual 12-ounce wax-coated paper cups containing greenhouse soil and arranged on a greenhouse bench. Normal daylight was supplemented and extended to 16 hours by banks of incandescent light bulbs to provide additional light during the winter months and to prevent flowering in the photoperiod sensitive cocklebur. The plants were sprayed in triplicate at the 2 to 3, 5 to 6, and 8 to 9 leaf stages with 100, 200, 400, 600, 800, and 1000 ppm diethanolamine salt of 2,4-D. The concentration of 2,4-D at which 50% of the plants were killed was determined at the end of 30 days. The tops of the cups were covered with paper towels at the time of treatment to prevent contamination of the soil.

For root application of 2,4-D the weeds were grown in aerated Hoagland's solution, using 7-liter glazed earthenware crocks with masonite lids holding four plants. Seventy plants of each species tested were grown until three or four mature leaves were present and then 2,4-D was added to the nutrient solution. Cocklebur received concentrations of 1, 2.5, 5, 7.5, 10, and 15 ppm; and jimson weed and bur cucumber were each given 15, 25, 50, 75, 125, and 175 ppm. Treatments were made in replicates of three jars containing a total of 10 plants. Two jars contained three plants each; the third contained four plants. The experiment was concluded at the end of 14 days, at which time the concentration necessary to effect a 50% kill was determined. A 50% kill was defined as that point at which one-half of the plants tested at a given rate were completely killed. At this point 100% of the cells had been destroyed and no living tissue was present.

Absorption of C^{14}-labeled 2,4-D by leaf and stem tissue.

Cocklebur, jimson weed, and bur cucumbers were grown in nutrient solution to the 4 to 5 leaf stage. Leaf tissue was punched from the periphery of the third and fourth leaves with a 13 mm cork borer. Stem tissue was taken from the upper two cm of the internode just beneath the bud. The tissue was cut into one mm sections which were pooled and rinsed very briefly in a glass of distilled water.

A two ppm solution of methyl-labeled 2,4-D (2,4-D-2-C^{14}) was prepared containing .001 M KH_2PO_4, .001 M calcium citrate, and .001 sucrose and adjusted to pH 5.0. Ten ml of this solution was placed in each of six petri dishes. Sixteen leaf discs or 100 stem sections of each species were floated in each dish. Four leaf discs or 20 stem sections were withdrawn at the time intervals indicated in Tables 1 and 2, rinsed thoroughly with distilled water, dried, and the radioactivity in the dried material determined with a thin window G-M tube. Radioactivity was determined on each leaf section separately, but five stem sections were pooled per planchet. Leaf discs harvested at four and eight hours were also analyzed for radiocarbon by collecting the CO_2 evolved by the Van Slyke combustion method

(7) and determining the radioactivity with a vibrating reed electroscope calibrated to disintegrations per second.

Absorption and translocation of radioactive 2,4-D in growing plants.

Cockleburs, jimson weeds, and bur cucumbers were grown to the 5-6 leaf stage in 6-inch clay pots. Twenty-four of the most uniform plants of each species were treated by pipetting 0.02 ml of 2000 ppm 2,4-D-1-C^{14}onto the midvein of the top mature leaf on each plant. The activity of the applied drop was 5855 disintegrations per second. Four plants of each species were segmented and dried at 1, 2, 4, 8, 12, and 24 hours after application of the 2,4-D. The individual portions of the plants analyzed for C^{14} by the Van Slyke wet combustion method included the lower half of the cotyledons with petioles, the lower half of each leaf with petioles, and the terminal bud. Also analyzed were 1 cm sections of the stem removed at the juncture of the petiole of the cotyledon and immediately above the level of the soil. The upper portion of the leaf containing the radioactive spot was clipped and discarded. The radioautograph of the bur cucumber harvested at 12 hours (Figure 1) was prepared from a previous experiment in which the plant was grown in nutrient solution and from which the treated portion was punched rather than clipped. It is given here to show the presence of 2,4-D in the roots.

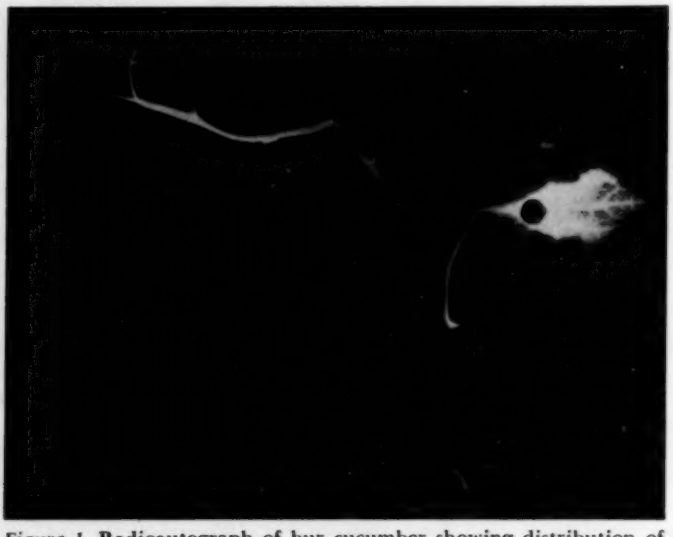

Figure 1. Radioautograph of bur cucumber showing distribution of 2,4-D-2-C at the end of 12 hours.

A duplicate set of plants was harvested, segmented, and dried. These were pressed between panes of glass on Kodak No-Screen X-Ray film and stored in a light-proof box for 32 days before developing.

Evolution of $C^{14}O_2$ derived from 2,4-D side-chain catabolism.

Eight plants each of jimson weed, cocklebur, and bur cucumber were grown to the four mature leaf stage in 6-inch clay pots. Using a micropipette, 0.03 ml of 2000 ppm methyl-labeled 2,4-D (2,4-D-2-C^{14}) was applied to the midvein of the top mature leaf of four plants of each species. A duplicate set was treated in the same manner using carboxyl-labeled 2,4-D (2,4-D-1-C^{14}). The activity of the applied drop was 3400 counts per minute for the methyl-labeled 2,4-D and 3000 for the carboxyl-labeled 2,4-D. The plants were placed in the light for eight hours. Cellulose acetate was then sealed across the top of the pot and about the base of the plant. A metal capsule having a diameter of one inch and containing one ml of 20% KOH was placed in the acetate at the base of each plant. A 2-quart jar was placed over each plant and capsule and sealed to the cellulose acetate with lanolin.

The plants were covered with pasteboard boxes to insure absolute darkness and left for 16 hours. The following morning, the capsules were removed, dried under a heat lamp, and the radioactivity of the evolved $C^{14}O_2$ was determined by a Geiger counter. The plants were again placed in the light for eight hours, and the cycle repeated. The experiment was terminated at the end of the third day.

Transmission of the 2,4-D stimulus across grafts of jimson weed and tomatoes and between branches in cocklebur.

Cockleburs were grown on a greenhouse bench. After all plants had attained a stage of growth in which two mature leaves were present, the terminal bud was removed, which resulted in the formation of two-branched plants. When each of the two branches possessed three or four mature leaves, the plants were treated in triplicate by 1. removing no leaves, 2. removing all leaves and the terminal bud from one branch, 3. removing only the terminal bud from one branch, and 4. removing the mature leaves but not the terminal bud from one branch. A solution of 1000 ppm 2,4-D amine was applied to all leaves of the opposite branch. Duplicate plants were tested in the above manner with one exception: treatment consisted of pipetting 0.03 ml of 2000 ppm 2,4-D-2-C^{14} on only the top mature leaf. Radioautographs were prepared from these plants at the end of 24 hours.

Jimson weed scions consisting of the terminal bud and one leaf were grafted to the decapitated tomato stocks. The leaves of the jimson weed scions were swabbed with cotton saturated with 1000 ppm 2,4-D to determine whether a sufficient portion of the herbicide would be translocated to kill the tomato stock.

RESULTS AND DISCUSSION

Screening various species for sensitivity to 2,4-D when application was made through the foliage and roots.

As indicated by greenhouse observations, the cocklebur was the most sensitive weed species (Figure 2). At all stages of growth tested

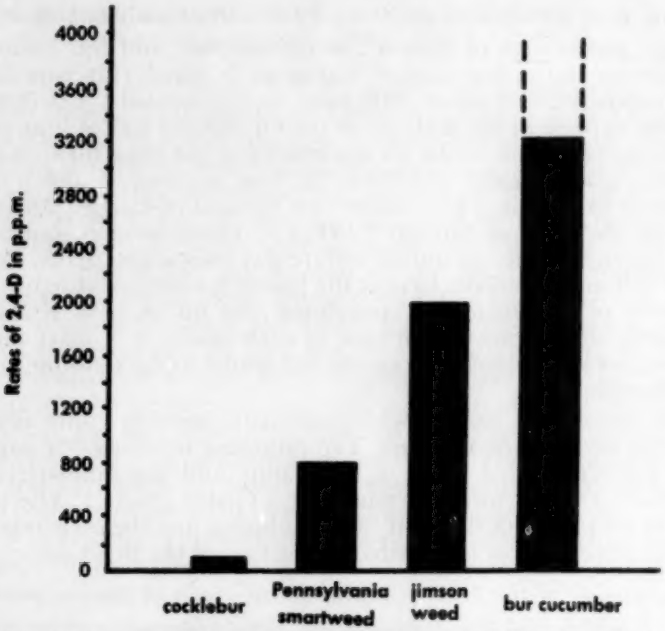

Figure 2. Concentration of 2,4-D diethanolamine applied as a foliage spray necessary to effect 50% kill.

(two to nine leaves) 100 ppm 2,4-D spray killed the plants in two weeks. Higher concentrations had a more rapid effect and the plants died within a few days. Plants receiving the lower concentrations showed a marked chlorosis, starting with the cotyledons and progressing upwards with time. Extensive stem proliferations accompanied the chlorosis. The stem attained an irregular diameter two to three times the normal size.

The concentration for a 50% kill in smartweed was 800 ppm. Lower concentrations did not completely kill the plants in 30 days, although severe epinasty occurred. There was little stem proliferation. Frequently associated with the heavier rates of 2,4-D was a rotting and decay of the stems at the soil level.

Jimson weed was initially sprayed with 2,4-D concentrations ranging from 100 to 1000 ppm, but these were increased when the highest rate failed to kill any of the plants. This species, as well as many other members of the Solanaceae, was characterized by severe malformations of stem and leaf even at very low rates of 2,4-D. Further growth did not occur when the plants received 400 ppm 2,4-D and above, although much higher concentrations did not kill the plants. When the 2,4-D concentration was increased to 2000 ppm, chlorosis appeared in the lower leaves and gradually proceeded upward. Plants receiving this concentration generally died within 25 to 30 days.

Bur cucumber was extremely resistant to 2,4-D. Concentrations of 4000 ppm not only failed to kill this species, but only caused a temporary inhibition of growth. Some proliferation occurred in the new leaves, but it was much less extensive than that found in the new leaves of jimson weed following treatment with only 100 ppm 2,4-D.

Although bur cucumber was resistant to 2,4-D, it was susceptible to 2,4,5-T. Concentrations of 500, 600, 700, and 800 ppm propylene glycol butyl ether ester of 2,4-D and 30, 40, and 50 ppm butyl ether ester of 2,4,5-T were sprayed on bur cucumber plants in the five to six leaf stage. The highest concentration of 2,4-D failed to cause more than epinasty and a temporary inhibition of terminal bud development. A rapid chlorosis appeared in the plants treated with 50 ppm 2,4,5-T. The chlorosis occurred in all leaves and plants receiving the highest concentrations died within three days. Chlorosis became evident in the 40 and 30 ppm groups in succession. At the end of nine days, a 100% kill had been achieved at all rates.

It was considered that the difference in sensitivity noted with the foliar sprays could be related to differential rates of absorption through the cuticle rather than to internal factors such as translocation or metabolism. For this reason the plants were exposed to varying concentrations of 2,4-D in the nutrient solution, thus circumventing the problem of cuticular transport (8).

The sensitivity of the weeds to 2,4-D remained in the same order as with foliar sprays (Figure 3). Cocklebur was again the most sensitive species. A 100% kill was obtained at 5 ppm and above. Roots of the plants receiving the four highest concentrations (5, 7.5, 10, and 15 ppm) turned from creamy white to brown within a few days after the 2,4-D was added. The roots were further characterized by decomposition and a notably slimy appearance.

Development of the terminal bud in jimson weed ceased at all concentrations used. All plants receiving 75 ppm and above were killed, while four plants died at 50 ppm. No losses occurred at 15 and 25 ppm. Roots of jimson weed assumed the same brown, rather slimy appearance noted in cockelbur. Plants receiving the 15 and 25 ppm 2,4-D failed to grow and assumed all the characteristics noted with foliage treatment with 1000 ppm: clasping leaves, proliferation of the stem, swelling of the terminal bud, and failure of additional leaf formation.

Bur cucumber was also killed completely at 75 ppm and above. Unlike jimson weed, growth at lower concentrations was only slightly curtailed, particularly at the 15 ppm rate. Although the roots were damaged at the two lower concentrations, the new roots formed at the water level and above. No new roots were noted in surviving cockleburs and jimson weeds.

The fact that the same order of sensitivity is found with foliar sprays and nutrient solution application indicates that a physical barrier to penetration of the herbicide is not the dominant factor in determining the relative susceptibility or resistance of these weeds to 2,4-D.

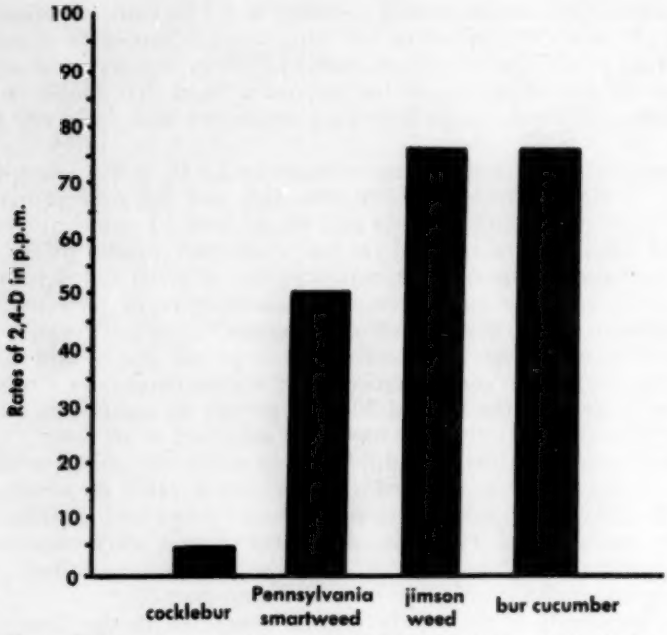

Figure 3. Concentration of 2,4-D diethanolamine in nutrient solution necessary to effect 50% kill.

Absorption of radioactive 2,4-D by leaf and stem sections.

In both stem and leaf sections, the two resistant species absorbed much more 2,4-D per milligram of dry weight than did cocklebur. As shown in Table 1, absorption in jimson weed and bur cucumber leaf disks was still continuing at the end of 24 hours, but the maximum had been reached in cocklebur at eight hours.

Table 1. Radioactivity of cocklebur, jimson weed, and bur cucumber leaf disks floated in a 2 ppm solution of 2,4-D-2-C^{14} for different lengths of time. Figures are averages of four replications.

Hours in solution	Counts per minute per milligram of dry weight		
	Cocklebur	Jimson weed	Bur cucumber
4	11.6	22.3	13.1
8	17.8	33.8	25.1
16	12.9	59.9	35.2
24	12.2	80.0	52.5

In stem sections (Table 2), little absorption took place in cocklebur after two hours. In the most resistant species, bur cucumber, 2,4-D uptake continued at a steady pace up to and including the termination of the experiment at eight hours.

Table 2. Radioactivity of cocklebur, jimson weed, and bur cucumber stem sections floated in a 2 ppm solution of 2-4-D-2-C^{14} for different lengths of time. Figures are averages of four replications.

Hours in solution	Counts per minute per milligram of dry weight		
	Cocklebur	Jimson weed	Bur cucumber
½	5.4	17.4	29.4
1	9.1	29.8	50.8
2	11.0	38.2	62.7
4	12.8	42.9	96.3
8	12.1	49.2	153.6

Because of the possibility of variation caused by thickness of leaf tissue, leaf disks at two time levels, four and eight hours, were analyzed by the Van Slyke wet combustion method. The four-hour samples showed a radioactivity of slightly over three disintegrations per second per milligram of dry weight in all three species. The eight-hour disks of jimson weed and bur cucumber had 7.4 and 7.6 disintegrations per second, respectively, while cocklebur had an activity of only 4.3. The differences in cellular absorption indicate a possible disruption in normal metabolic activity in cocklebur. The process by which the 2,4-D enters the cell and is rendered neither diffusable nor exchangeable (6) is more pronounced in jimson weed and bur cucumber. In both leaf and stem sections of cocklebur 2,4-D concentrations within the leaf fell after reaching a peak, suggesting some damage to the ion retention mechanism.

These results strongly suggest that factors other than the amount of cellular absorption are responsible for herbicidal activity by 2,4-D in these weed species. Results obtained in this experiment were the reverse of what one would expect if herbicidal action was directly proportional to the amount of 2,4-D absorbed. Quantity absorbed did not seem to bear any relationship to sensitivity or resistance.

Absorption and translocation of radioactive 2,4-D by growing plants.

It had already been established in the preceding experiment with leaf disks and stem sections that major differences existed among these three species in the quantity of 2,4-D they would absorb, The following test more closely approached conditions as they would be normally encountered in the field and provided both a quantitative and visual observation of the movement of the herbicide within the plant.

Following treatment with 2,4-D-2-C^{14}, duplicate plant parts were pooled into samples averaging 10–15 mg of dry weight. These were analyzed for activity per milligram of dry weight. Because of the low activity and background variability, readings of less than one were recorded as zero. In Table 3 "stem" refers to the section of the stem taken at the cotyledons and "base" to the stem section taken at the soil level.

As noted in previous work, 2,4-D did not enter mature leaves or cotyledons located beneath the point of application during the 24-

Table 3. Radioactivity in disintegrations per second per milligram of dry weight of different sections of cocklebur, jimson weed, and bur cucumber following treatment with 0.02 ml 2,4-D-2-C^{14}.

Time of harvest hours	Plant segment	Disintegrations per sec per mg dry wt		
		Cocklebur	Bur cucumber	Jimson weed
1		0	0	0
2		0	0	0
4	Treated leaf	2.3	9	1.9
8	Treated leaf	2.8	4.0	2.8
	Bud	3.7	1.7	1.3
	Stem	1.1	4.0	0
	Base	0	1.5	0
12	Treated leaf	8.8	16.1	8.8
	Bud	2.5	11.8	8.8
	Stem	2.7	4.6	21.9
	Base	0	1.3	2.1
24	Treated leaf	8.9	25.6	27.0
	Bud	15.1	14.2	13.9
	Stem	6.5	6.8	17.7
	Base	3.0	2.4	6.6

hour test period. Analysis of these parts failed to show the presence of C^{14}.

No quantities of C^{14} in amounts approaching one disintegration per second per milligram of dry weight were present in any of the one- and two-hour samples. By the eighth hour, considerably more C^{14} was found throughout bur cucumber than in cocklebur. At 12 hours, there was more than twice as much C^{14} throughout the two resistant species as in cocklebur.

Radioautographs showed at least traces of 2,4-D in the stems of all species in as little as four hours. The more resistant species appeared to be translocating the chemical slightly more rapidly than was cocklebur.

These results indicate that jimson weed and bur cucumber are not resistant because they fail to absorb and translocate 2,4-D. At least through 24 hours, cocklebur lagged behind the more resistant species in total amount of 2,4-D translocated.

Evolution of $C^{14}O_2$ from 2,4-D-2-C^{14} and 2,4-D-1-C^{14} side-chain catabolism.

Data obtained from this experiment (Table 4) indicated that differences in $C^{14}O_2$ evolution were so slight in comparison with

Table 4. Radioactive carbon dioxide evolved from cocklebur, jimson weed and bur cucumber following 16 hours of darkness. Counts per minute at 950 volts.

Plant	First day		Second day		Third day		Orig. activity	
	1-C[a]	2-C[a]	1-C	2-C	1-C	2-C	1-C	2-C
Cocklebur	8	5	9	6	5	7	3000	3400
Bur cucumber	12	7	11	9	8	8	3000	3400
Jimson weed	7	8	5	5	5	5	3000	3400

[a] 1-C and 2-C refer to 2,4–D–1–C^{14} and 2,4–D–2–C^{14}.

the amount absorbed that side-chain metabolism did not appear to be a factor in explaining the phenomenon of resistance or sensitivity. This is in agreement with Weintraub (9), who also found little difference in the rate of breakdown between resistant and susceptible species.

An analysis of leaf disks taken at the point of application showed that an average of 47–48% of the 2,4-D was absorbed and translocated at least ½ centimeter away from the original spot. The differences in $C^{14}O_2$ evolution among the three species was negligible, varying by fractions of one percent against the total activity present within the plant.

Transmission of 2,4-D between branches and across grafts.

Cocklebur plants on which the untreated branches had either been defoliated (Treatment 2) or had the mature leaves removed (Treatment 4) died within two weeks. Death was primarily due to lack of photosynthetic capacity brought about by herbicidal destruction of all the leaves on the treated branch.

Plants from which no leaves (Treatment 1) or only the terminal bud (Treatment 3) had been removed from the untreated branch did not die. Although the treated branches died within two weeks, there was no evidence that 2,4-D was translocated into the untreated branches. Proliferations extended down the stems only on one side, suggesting that the growth-regulator was largely confined to the stem phloem tissues directly connected with the treated branches. There was neither chlorosis of leaves nor proliferation in the untreated branches, and growth was only slightly retarded.

Radioautographs showed virtually no 2,4-D in the untreated branch at 24 hours when mature leaves were present (Treatment 1) or when it had been completely defoliated (Treatment 2). Only when the mature leaves had been removed, leaving meristematic tissue on the untreated branch (Treatment 4) was any translocation noted.

Treatment of jimson weed scions with 1000 ppm 2,4-D failed to cause more than minor proliferations in the tomato stock near the graft union. In a subsequent test, 10–12 inch tomatoes were sprayed with 1000, 1200, 1400, 1600, and 1800 ppm 2,4-D as the diethanolamine salt. Although the tomatoes were highly responsive at all concentrations, no deaths occurred within 30 days. This suggests there may be a response to 2,4-D based on botanical relationship. Many members of the Solanaceae are easily damaged but difficult to kill.

The differences in sensitivity or resistance observed in cocklebur, jimson weed, and bur cucumber appeared to be physiological in nature and bore no relationship in the quantity of 2,4-D absorbed and translocated within the plant. Bur cucumber was virtually indestructible when 2,4-D was applied to the foliage, yet was quite susceptible to 2,4,5-T.

One of the phenomena noted in all species tested was epinasty in leaves and stem. This response to 2,4-D is most marked in the supple stems and long petioled leaves of bur cucumber. The most serious effect caused by 2,4-D in cocklebur was its capacity to destroy the

leaves. The severe chlorosis may have been an immediate effect on leaf chlorophyll or a disruption of mineral translocation because of stem proliferations. The fact that chlorosis progressed from the bottom leaf upward would suggest the latter.

The failure of 2,4-D to be translocated to an untreated branch whose photosynthesizing leaves were causing a vigorous downward movement of carbohydrates may in part explain the failure to obtain complete kills in dense stands of weeds whose underlying branches are not easily reached by the herbicide. When one branch of cocklebur receives 10 times the concentration necessary to kill an entirely-sprayed plant, only the treated branch and one-half the stem dies. The complete normality of the opposite side of the stem and the absence of leaf proliferations on the untreated branch two months after treatment suggests that the chemical does not enter the xylem in significant quantities.

Since nearly all biochemical reactions are enzymatically controlled, the answer to differences in plant resistance probably lies in discovering the enzyme systems concerned with 2,4-D catabolism, or which are inhibited by the herbicide. Resistance could be caused by the presence of enzyme systems capable of rapid alteration of the molecule into a nontoxic form. Resistance could also be brought about by the presence of enzymes whose biochemical nature is such that 2,4-D cannot inhibit their normal function. Future work comparing enzyme systems and 2,4-D metabolites would prove invaluable in clarifying sensitivity vs. resistance in these species.

SUMMARY

1. Weed species which were resistant or sensitive to 2,4-D when application was made through the foliage tended to react in a similar manner when the herbicide was absorbed through the roots.

2. Leaf disks and stem sections of jimson weed and bur cucumber absorbed considerably more 2,4-D when placed in a 2 ppm solution of methyl-labeled 2,4-D than did cocklebur. Absorption in cocklebur ceased after a relatively small quantity of the growth-regulator had been absorbed.

3. Plants of jimson weed and bur cucumber absorbed and translocated greater quantities of 2,4-D during a 24 hour period than cocklebur.

4. Evolution of $C^{14}O_2$ from 2,4-D side-chain catabolism did not differ significantly among species. The amount recovered was extremely low in comparison with total 2,4-D absorbed.

5. Transmission of 2,4-D to an untreated branch of cocklebur was negligible if that branch had several mature leaves. 2,4-D seemed confined to the conductive tissues directly connecting the stem and treated branch.

6. Tomatoes, while ruined commercially at relatively low 2,4-D concentrations, were not easily killed upon reaching a height of 10–12 inches. Their resistance to kill at this stage compared to jimson weed in the 5–6 leaf stage.

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Chemical Control of Barnyardgrass in Rice[1]

ROY J. SMITH, JR.[2]

BARNYARDGRASS *(Echinochloa crusgalli* (L.) Beauv.) is the most serious weed in rice in Arkansas and this and other species of *Echinochloa* are a serious problem throughout the rice-growing areas of the world. A limited field survey conducted in August 1957 in the Grand Prairie rice-growing region of Arkansas indicated that 27 percent of the rice fields were infested with barnyardgrass. Presumably the yield of rice on these fields could have been increased substantially by controlling the barnyardgrass.

Investigations in Louisiana (1) indicated that isopropyl *N*-(3-chlorophenyl)carbamate (CIPC), sodium trichloroacetate and sodium 2,2,3–trichloropropionate applied 3 days after emergence of rice gave satisfactory barnyardgrass control without reducing yields of rice. However when applications were made 7 to 14 days after emergence the chemicals were ineffective.

In Venezuela annual grasses such as barnyardgrass and crabgrass were controlled effectively in upland rice with pre-emergence to emergence applications of CIPC and 4,6-dinitro-*o*-sec-butylphenol (DNBP) (5). Even though annual grasses emerged late in the growing season, treatments with herbicides increased yields of rice substantially.

The purpose of this investigation was to evaluate chemicals and methods for the control of barnyardgrass in rice and factors that influence their use.

METHODS AND MATERIALS

Chemical methods of controlling barnyardgrass in rice were evaluated in the field during a 4-year period, 1955–58. Practices that influenced the control of barnyardgrass in rice are discussed individually.

Numerous experiments were conducted on Crowley silt loam and Sharkey clay in Arkansas and Lincoln counties, respectively. The Zenith and Bluebonnet 50 varieties of rice were seeded during May of each year. The rice was drill- and broadcast-seeded at depths ranging from ½ to 2 inches and ¼ to 1 inch, respectively, at rates of 100 to 135 lb/A. Three or four replications arranged in either randomized-complete-block or split-plot designs were used. The chemicals were applied as a spray in a total volume of 5 to 40 gallons per acre at various rates to rice at stages of growth that ranged from pre-emergence to early post-emergence.

The type and quantity of fertilizer applied to the plots in each experiment were based on soil test. In most experiments phosphate

[1]Cooperative investigations of the Crops Research Division, A.R.S., U.S.D.A. and the Arkansas Agr. Exp. Sta.

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was applied before seeding by broadcasting at rates of 30 to 50 lb/A and nitrogen was applied as a topdressing at rates of 45 to 70 lb/A.

RESULTS AND DISCUSSION

Effect of chemical and rate.

The chemicals and rates studied are listed in Table 1. The highest degree of barnyardgrass control and the highest yield of rice were obtained from plots treated with CIPC (Table 1). CIPC, DNBP,

Table 1. Effect of herbicides applied at different rates on the control of barnyardgrass and the yield of rice, 1956.

Herbicide and rate lb/A	Control of barnyardgrass percent	Yield of rice[a] bu/A
None	0	36.8
CIPC		
4	64	78.7
6	68	83.9
8	76	83.7
Mean	70	82.1
DNBP		
4	34	61.6
6	36	70.9
8	32	67.8
Mean	34	66.8
CIPC+DNBP		
2+2	46	70.6
3+3	57	78.3
4+4	51	74.6
Mean	51	74.5
PCP		
7	4	44.8
14	31	63.8
21	38	78.4
Mean	24	62.3

[a]LSD for herbicide means: 5% level 6.3 bu/A; 1% level 8.4 bu/A

LSD for herbicide x rate means: 5% level 11.0 bu/A; 1% level 14.5 bu/A

CIPC + DNBP, and the sodium salt of pentachlorophenol (PCP) gave 70, 34, 51, and 24 percent control of barnyardgrass, respectively, and yield increases compared with no treatment of 45.3, 30.0, 37.7, and 25.5 bu/A, respectively. A mixture of CIPC + DNBP was less effective than CIPC alone but more effective than DNBP alone. Yield differences were nonsignificant for different rates of CIPC, DNBP, and CIPC + DNBP, but as the rate of PCP increased yield of rice was increased significantly with each successive increase in rate.

DNBP injured rice when the moisture content of the soil was high at time of treatment and high temperatures followed application. The injury was manifested by burning of the rice seedling, which ultimately ended in kill, and as a result the stand of rice was reduced greatly. Apparently this injury was due to water-vapor distillation of DNBP from the soil under conditions of ample soil moisture and air temperatures above 90°F (2, 4).

Since 1956 data indicated that CIPC was more effective than other

chemicals for controlling barnyardgrass in rice, further investigations were conducted with it in 1957 and 1958. The rates of CIPC used in these studies are given in Table 2. As the rate of CIPC

Table 2. Effect of CIPC applied at different rates on control of barnyardgrass and yield of rice, 1957 and 1958.

Year and rate CIPC lb/A	Control of barnyardgrass[a] percent	Yield of rice,[a] bu/A
1957		
0	0 a	55.8 a
4	72 b	91.2 b
6	82 c	96.4 bc
8	93 d	100.1 c
10	98 d	100.3 c
1958		
0	0 a	56.2 a
4	39 b	79.0 b
6	55 c	84.2 c
8	62 d	88.2 d
10	69 e	92.1 d

[a]Values followed by different letters differ significantly at the 5- percent level of probability. Values followed by the same letter are not significantly different.

increased, control of barnyardgrass was successively better. In 1957 yields from plots sprayed with 8 and 10 lb/A were significantly better than those from plots sprayed with 4 lb/A. In 1958 yields were increased significantly with each sucessive rate of 4, 6, and 8 lb/A but no significant difference was obtained between 8 and 10 lb/A (Table 2). The CIPC treatment resulted in excellent control of barnyardgrass (Figure 1) and significant increases in the yield (Table 2) of rice.

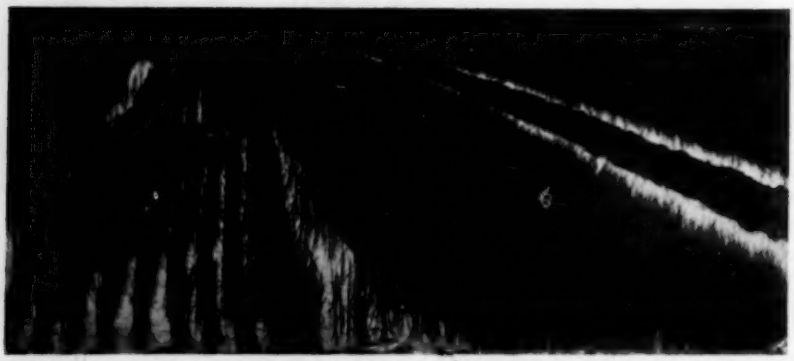

Figure 1. Control of barnyardgrass in rice with CIPC. Plots sprayed with 8 lb/A of CIPC (left) and unsprayed (right).

The data suggest that on areas on which barnyardgrass infestations are heavy, yields of rice may be greatly increased by controlling the grass chemically. In addition the data illustrate the competitiveness of barnyardgrass with rice. CIPC gave better control of barnyardgrass and less injury to rice than the other chemicals evaluated. These experiments indicate that 6 to 8 lb/A of CIPC give sufficient barn-

yardgrass control to permit the production of nearly maximum yields of rice. Rates of CIPC lower than 6 lb/A may be insufficient to control the grass adequately and rates higher than 8 lb/A in most instances probably would not give sufficient returns to justify the increased rate even if the higher rate did not injure the rice.

Effect of depth of seeding.

Zenith rice was seeded ½, 1, and 2 inches deep and sprayed with 0, 6, and 12 lb/A of CIPC applied when the rice was emerging. The unsprayed plots were kept free of weeds by hand weeding and by water management. The plots were irrigated 1, 3, and 6 days after herbicide treatment in order to keep the soil saturated. Under these conditions the downward movement of CIPC in the soil should have been maximum.

With both rates of CIPC the stand of rice was affected less as the depth of seeding increased and at equivalent depths, 6 lb/A of CIPC caused less stand reduction than 12 lb/A (Figure 2). A significant

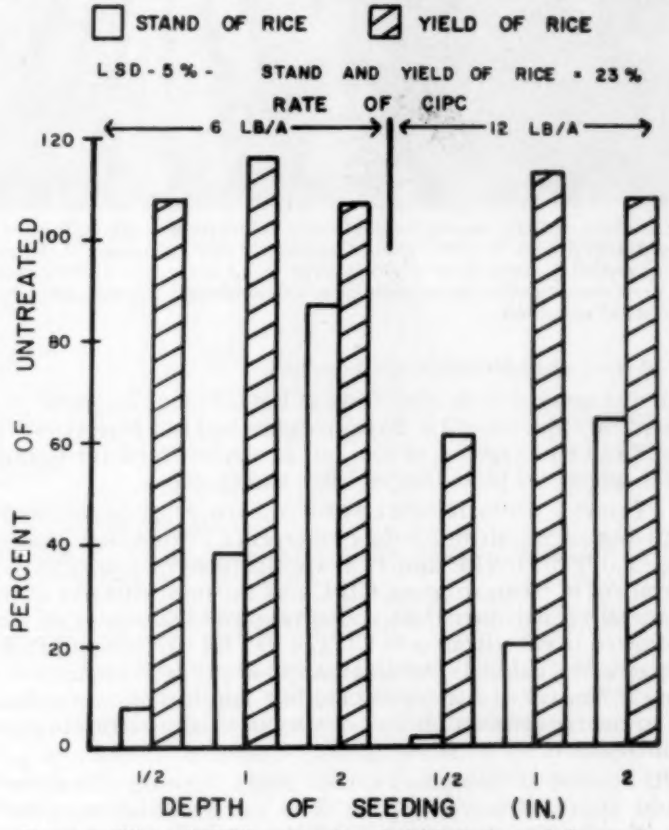

Figure 2. Effect of CIPC on stand and yield of rice as influenced by depth of seeding, 1958.

yield reduction was obtained only on plots seeded ½ inch deep and sprayed with 12 lb/A of CIPC (Figure 2). Figure 3 shows the appearance of the plots seeded at different depths and sprayed with 6 lb/A of CIPC. Where the stand was reduced, plants compensated for the loss by increased tillering; consequently, yields were not affected greatly.

Figure 3. Effect of CIPC on rice as influenced by depth of seeding. Treated plots sprayed with 6 lb/A of CIPC applied at time of rice emergence. 1. Untreated. 2. Rice seeded ½ inch deep showing large stand reduction. 3. Rice seeded 1 inch deep showing some stand reduction. 4. Rice seeded 2 inches deep showing slight stand reduction.

Effect of time of application of chemicals.

Rice was sprayed with chemicals at the different stages of growth indicated in Tables 3 and 4. Barnyardgrass had not emerged on plots sprayed before emergence of rice but it was emerged (first- and second-leaf stages) on plots treated after emergence.

On a Crowley silt loam best control of barnyardgrass was obtained by applying chemicals just before emergence to complete emergence of rice (Table 3). DNBP and PCP applied pre-emergence gave very little control of barnyardgrass. CIPC was the most effective chemical for controlling barnyardgrass and giving yield increases of rice. It was followed in effectiveness by CIPC + DNBP, DNBP, and PCP. On a Sharkey clay (Table 4) chemicals applied pre-emergence gave very ineffective control of barnyardgrass, but application when the rice began to emerge caused sufficient control of barnyardgrass to produce yield increases of 35 to 46 bu/A.

CIPC applied at emergence caused slight burning along the margins and apices of leaves of rice. The rice seedlings outgrew this injury shortly after treatment. DNBP and PCP injured emerging rice as manifested by contact burning of the seedling. Usually these

Table 3. Effect of time of application of herbicides on the control of barnyardgrass and yield of rice on a Crowley silt loam, 1956.

Herbicide	Stage of rice at time of spraying				
	Pre-emergence[a]	Just before[b] emergence	20–30%[c] emergence	100%[d] emergence	Mean[e]
	Barnyardgrass control, percent				
CIPC	66	68	70	75	70
DNBP	18	41	43	34	34
CIPC+DNBP	39	53	56	56	51
PCP	10	33	22	31	24
Mean	33	49	48	49	—
	Yield of rice, bu/A				
None	38.0	37.0	37.9	34.3	36.8
CIPC	78.1	82.7	81.8	85.7	82.1
DNBP	46.9	68.2	73.1	79.0	66.8
CIPC+DNBP	63.1	77.6	76.4	80.8	74.5
PCP	45.7	62.9	69.6	71.1	62.3
Mean[f]	58.4	72.8	75.2	79.2	—

[a]Immediately after seeding.
[b]Approximately 1 day before emergence.
[c]Rice, which was emerged, had been emerged approximately 1 day.
[d]Rice was emerged 1 or 2 days.
[e]LSD for herbicide means: 5% level . . . . . 6.3 bu/A
1% level . . . . . 8.4 bu/A
[f]Excludes value for none.

Table 4. Effect of time of application of herbicides on the control of barnyardgrass and yield of rice on a Sharkey clay, 1956.

Herbicide[a]	Stage of rice at time of spraying	
	Pre-emergence[b]	Emergence[c]
	Barnyardgrass control, percent	
CIPC	4	54
DNBP	20	58
CIPC+DNBP	6	59
Mean	10	57
	Yield of rice, bu/A	
None	41.5	44.1
CIPC	45.2	79.2
DNBP	57.8	90.7
CIPC+DNBP	40.8	88.0
Mean[d]	47.9	86.0

[a]Mean of 6 and 8 lb/A treatments.
[b]Immediately after seeding.
[c]Rice 10 to 20 percent emerged—emergence complete 1 or 2 days after treatment.
[d]Excludes values for none.

contact chemicals, DNBP and PCP, caused greater injury to emerged rice than CIPC.

In certain studies for which data are not presented, CIPC applied immediately after seeding of rice caused substantial injury to it, especially when rainfall occurred soon after application. In other investigations barnyardgrass which had reached the third- or fourth-leaf stages (2 to 4 inches high) was not controlled satisfactorily by application of CIPC. Baker (1) reported that applications of CIPC to large grass gave ineffective control. Since the time of application of CIPC appears to be very critical for obtaining maximum control

of barnyardgrass and since extensive observations over the rice-growing areas of Arkansas show that the comparative times of emergence of rice and barnyardgrass vary with soil moisture, soil type, and possibly other factors, it may be advantageous to apply CIPC at a time based on the growth stage of barnyardgrass rather than on that of rice growth. For example, if soil moisture is adequate immediately after seeding of rice, barnyardgrass usually emerges before the rice, especially on clayey soils. If spray applications were made on the basis of stage of growth of barnyardgrass, presumably best control might be obtained by treating immediately after emergence of the first barnyardgrass. At this time the rice may range from pre-emergence (just below the soil surface) to complete emergence.

Applying CIPC on the basis of the stage of growth of barnyardgrass may have an added advantage since the barnyardgrass infestation may be determined before treatment. Thus from a commercial usage standpoint the need for control of the barnyardgrass could actually be determined before applying the herbicide. Such information would prevent the use of the herbicide unnecessarily on fields or parts of fields that were not grassy or during years when weather conditions were unfavorable to barnyardgrass germination and growth.

Effect of water management.

In an early investigation rice was injured when it was irrigated immediately after CIPC treatment, but the soil was cracked due to sun-baking.

Thus in 1957 and 1958 investigations were conducted to determine whether time of irrigating after spraying influenced the response of rice or barnyardgrass to CIPC. The various water-management practices investigated are listed in Table 5. In 1957 approximately

Table 5. The effect of water management following CIPC application[a] on control of barnyardgrass and yield of rice, 1957 and 1958.

Year and water management	Control of barnyardgrass percent	Yield of rice bu/A
1957		
Irrigation applied 1 day after spraying[b]	86	89.4
Irrigation applied 6 days after spraying[c]	87	87.5
Flood applied 14 days after spraying	92	89.5
Flood applied 20 days after spraying	81	88.6
LSD	N.S.	N.S.
1958		
Irrigation applied 2 days after spraying[d]	56	80.0
Flood applied 2 days after spraying	85	90.1
Flood applied 12 days after spraying	61	84.2
Flood applied 21 days after spraying	23	65.4
LSD 5% level	6	10.4
LSD 1% level	9	14.9

[a]Rice and barynardgrass had emerged at time of spraying.
[b]Plots flooded and drained as soon as the soil was saturated and flooded 14 days after CIPC treatment.
[c]Plots sprinkle-irrigated with sprinkling system to saturate soil and flooded 14 days after CIPC treatment.
[d]Plots were flooded and drained as soon as the soil was saturated and flooded 23 days after CIPC treatment.

3 inches of rain and in 1958 no rain fell during the 10 days after spraying. When ample moisture was present in the soil as in 1957 control of barnyardgrass was 80 percent or more irrespective of water management after spraying (Table 5), but when the soil was dry, as in 1958, control of barnyardgrass was decreased with delayed irrigation and this situation was especially apparent with the 21-day flooding (Table 5 and Figure 4). The data imply that ample moisture must be present in order to activate CIPC. If the soil surface becomes sun-baked because of lack of rainfall, irrigation is required in order to obtain adequate barnyardgrass control. Irrigation following soon

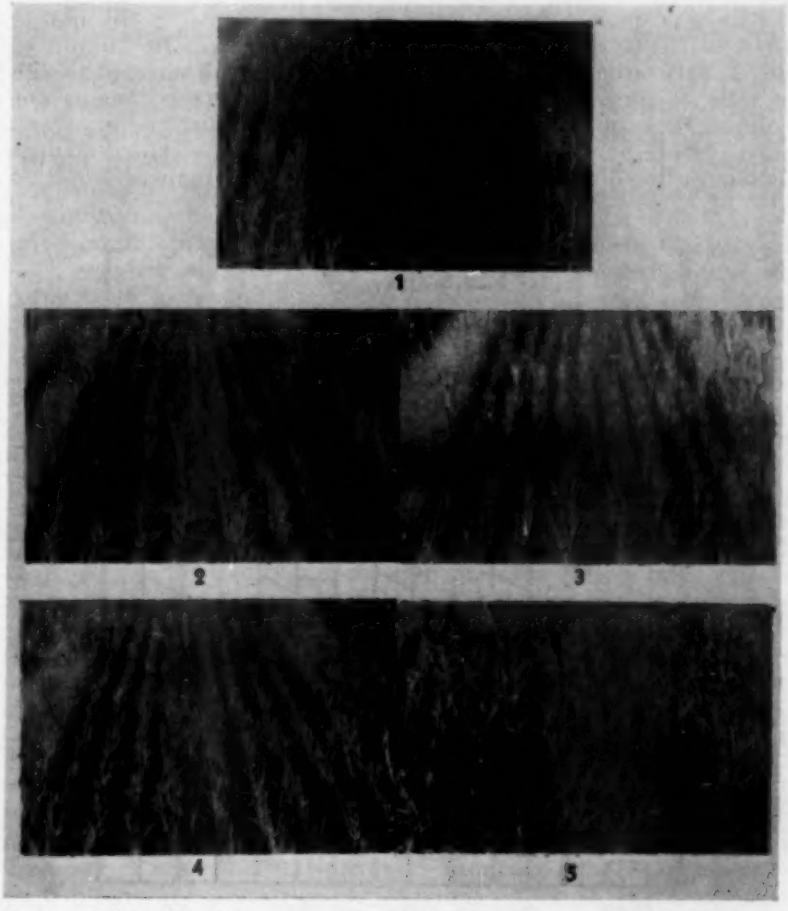

Figure 4. Effect of water management after CIPC treatment on control of barnyardgrass. 1. Untreated plot showing barnyardgrass infestation. 2. Irrigation applied 2 days after spraying. 3. Flood applied 2 days after spraying. 4. Flood applied 12 days after spraying. 5. Flood applied 21 days after spraying. All treated plots show good to excellent barnyardgrass control except 5.

after CIPC treatment did not injure rice provided it was seeded below 1 inch deep.

On the basis of all investigations, the soil must contain adequate moisture if satisfactory barnyardgrass control is to be obtained. If moisture is not provided by rainfall, it must be applied by irrigation. Soil moisture must be ample before the barnyardgrass becomes too large or before the chemical is deactivated in the soil. Apparently CIPC is deactivated either by volatilization or microbial decomposition or a combination of these within 2 to 3 weeks after its application to the soil.

Effect of spray volume.

Rice was sprayed at early post-emergence with 6, 8, 10 and 12 lb/A of CIPC, each applied in total volumes of 5, 10, 20 and 40 gal/A. Barnyardgrass was in the first- and second-leaf stages of growth at time of spraying. There was very little difference among the volumes of application as to the efficiency of control of barnyardgrass (Figure 5). Application of CIPC in 40 gal/A caused slightly better control of barnyardgrass and yield of rice than in 5 and 10

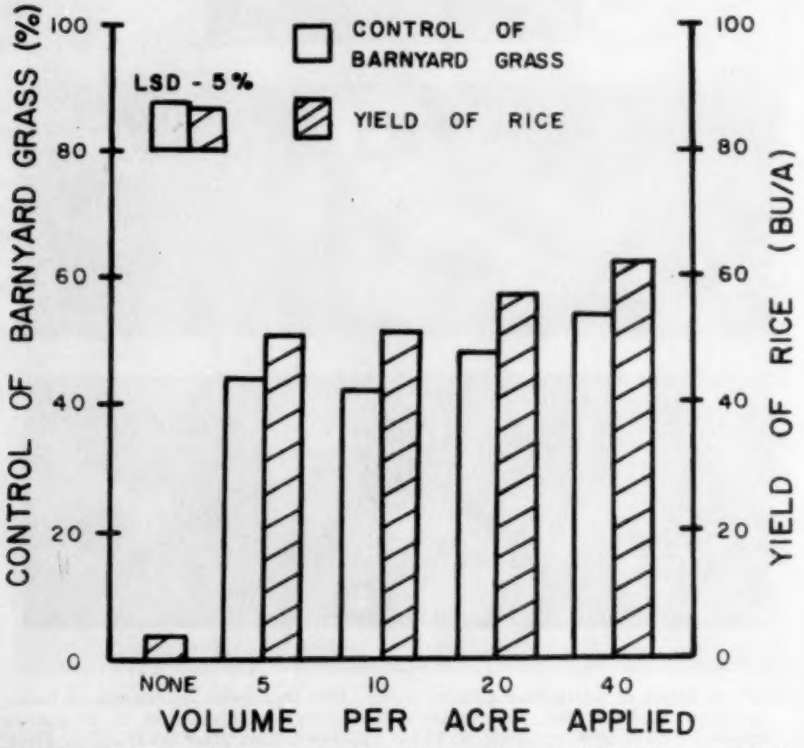

Figure 5. Effect of volume of spray (gal/A) on efficiency of CIPC for control of barnyardgrass in rice. Values are composite data for all rates of application.

gal/A (Figure 5). Stand of rice was reduced slightly on plots treated with CIPC applied in 5 gallons per acre.

In certain other experiments, in which volume of spray was 10 gallons per acre, satisfactory barnyardgrass control with little injury to rice was obtained. Provided the spray was uniformly applied to the soil, control of barnyardgrass was satisfactory with 10 to 40 gallons of spray per acre. Ennis (3) indicated that if spray coverage is uniform CIPC may be applied pre-emergence in 20 gallons per acre of water without reducing weed control efficiency and without increasing hazard to soybeans. The studies reported herein indicate that if spray coverage is uniform CIPC may be applied early post-emergence in a volume of 10 gallons per acre without serious reduction in grass-control efficiency and without increased hazard to rice.

Effect of formulation of CIPC.

A granular formulation of CIPC has effectively controlled weeds in certain nursery crops and since CIPC may be applied advantageously by airplane, an investigation was conducted to evaluate comparatively the granular and emulsifiable formulations of CIPC for controlling barnyardgrass in rice.

A 5 percent granular (Attaclay, RVM, 24/48 mesh) formulation of CIPC was broadcast by hand at 5 to 7 lb/A (actual CIPC) and the emulsifiable formulation was sprayed at 6 lb/A. The treatments were made when the rice was in the second-leaf stage and the barnyardgrass was in the first- to third-leaf stages.

Rainfall soon after application washed the granules of CIPC into the low areas of the plots causing a low concentration in the high areas and a high rate in the low areas. Thus the barnyardgrass was not controlled uniformly throughout the plot, and the rice was injured in locations where the concentration of CIPC was high. The granular formulation produced 50 to 60 percent control of barnyardgrass while the emulsifiable formulation gave 60 to 70 percent control. Since the seedlings of barnyardgrass were rather large at time of treatment only part were killed, but part were inhibited severely which reduced their competitiveness with rice. Plots treated with granular and emulsifiable formulations yielded an average of 80.8 and 102.0 bu/A, respectively, as compared with 77.8 bu for the untreated plots.

Effect of soil type.

The efficiency of CIPC for controlling barnyardgrass in rice was compared on Crowley silt loam and Sharkey clay and the results are reported in Table 6. Data for each year indicate that CIPC controlled barnyardgrass more effectively, with resulting greater increases in yield of rice, on the Crowley silt loam than on the Sharkey clay. Even though yields were increased less on the Sharkey clay than on the Crowley silt loam, they were increased significantly. These data suggest that higher rates of CIPC are required on clay than on lighter soils.

Table 6. Effect of soil type upon the efficiency of CIPC for control of barnyardgrass in rice, 1956 and 1957.[a]

Year and soil type	Control of barnyardgrass percent	Rice yield	
		bu/A	Increase over untreated percent
1956			
Crowley silt loam	76	84	128
Sharkey clay	54	79	80
1957			
Crowley silt loam	82	96	73
Sharkey clay	62	102	31

[a]Rates of 6 and 8 lb/A were averaged in 1956 but only 6 lb/A was used in 1957.

Response of rice to CIPC.

The results of all the experimentation reported herein would indicate that rice is relatively susceptible to CIPC when roots of the crops are in contact with the chemical. Selectivity of rice and barnyardgrass appears to be based primarily on the differential location of germinating seed and feeding roots of these species in the soil. Rice seeded ½ inch deep was injured severely by CIPC, but that seeded 1 to 2 inches deep was injured only slightly. In the field the majority of seed of barnyardgrass germinate within the surface ½ inch layer of soil. When roots of rice or barnyardgrass come into contact with CIPC, the chemical is absorbed and injury to the seedlings result. Seeding rice 1 to 2 inches deep protects it from CIPC since the chemical is localized in the surface inch layer of soil (6) and feeding roots are located below this zone.

SUMMARY

A four-year study on the chemical control of barnyardgrass in rice and an evaluation of practices that affect the use of chemicals for the control of barnyardgrass in rice was conducted at Stuttgart, Arkansas. These investigations may be summarized as follows:

1. CIPC was superior to DNBP, a mixture of CIPC + DNBP, and PCP for control of barnyardgrass in rice.

2. The degree of control of barnyardgrass obtained with 6 and 8 lb/A of CIPC resulted in maximum yields of rice.

3. Rice seeded ½ inch deep was injured severely by CIPC, but that seeded 1 and 2 inches deep was injured only slightly.

4. CIPC, DNBP, a mixture of CIPC + DNBP, and PCP gave best control of barnyardgrass when applied about the time of emergence of rice and barnyardgrass. Since soil and climatic factors influenced the comparative time of emergence of rice and barnyardgrass, the most effective grass control was obtained by spraying with CIPC when the barnyardgrass was just emerging through the soil. Barnyardgrass was not controlled when sprayed at the third- or fourth-leaf stages.

5. Water management after application of CIPC did not influence the control of barnyardgrass when the soil remained moist because

of timely rainfall. However, when the soil sun-baked soon after spraying irrigation was essential for satisfactory control.

6. Control of barnyardgrass and yields of rice were increased slightly as spray volumes of CIPC were increased from 5 to 40 gallons per acre. However, satisfactory control of barnyardgrass was obtained with all these volumes.

7. The emulsifiable formulation of CIPC controlled barnyardgrass in rice more effectively than the granular under the conditions of these studies.

8. The efficiency of CIPC at 6 to 8 lb/A for controlling barnyardgrass in rice was greater on a Crowley silt loam than on a Sharkey clay. However, CIPC controlled barnyardgrass satisfactorily on both soil types.

9. Rice was injured by CIPC when its roots were located in the treated area. The main basis of selectivity of rice and barnyardgrass appeared to be differential depth in location of feeding roots in the soil. Protection of rice from the chemical was obtained by deep seeding.

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Russian Knapweed Control with Cultivation, Cropping and Chemicals[1]

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ALTHOUGH Russian knapweed is not as widespread as some of the other deep-rooted perennial weeds, thousands of acres of farmland are infested and it is spreading. It is generally called *Centaurea repens* L., according to Fernald (3) and Stevens (8), though it also is referred to as *C. picris* Pall. Stevens states that there is some question about the identity of *C. repens.*

Fernald (3) states that it is rapidly spreading and can be found in the area bounded by Michigan on the east, Washington on the west and south to Missouri, Texas and California. However, the Dakotas, Nebraska and Kansas are the only North Central States that report having it[3]. It is also present in the Prairie Provinces of Canada. Stevens (8) describes it as a "gray perennial from deep horizontal, black roots with stems 3–8 decimeters high, often much branched; leaves 3–8 centimeters long, lanceolate, the lower broader and frequently pinnately lobed; heads 1 centimeter wide, rose colored to nearly white." Rogers (7) describes the flower of *C. picris* Pall. as being lilac-colored and elaborates about the gray nap on stem and leaves. They (3, 7, 8) do not mention the bitter taste of the upper leaves that has been observed by the authors.

Frazier (5) studied the root development of noncompeting Russian knapweed seedlings growing in a sandy loam soil. He found that a very extensive root system was developed in a short time. Buds developed on the roots and produced rhizomes which initiated shoots when they reached the soil surface.

Very few data could be found in the literature to serve as a guide when planning the study. However, the studies by Rogers (7) and Frazier (5) indicated that Russian knapweed was similar to leafy spurge and field bindweed. Methods of eliminating field bindweed and leafy spurge were reviewed by Derscheid et al. (2). These methods included the use of intensive cultivation alone; the use of cultivation and summer planted competitive crops; cultivation, grain crops and 2,4-D and perennial forage crops with and without cultivation or 2,4-D.

Timmons and Brun (9) reported that Russian knapweed was eliminated by cultivation at 3-week intervals for a period of 2 years, but Warren and Freed (10) indicated that 10 to 12 cultivations for 2 or 3 years were required.

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[1]Approved for publication by the Director of The South Dakota Agr. Exp. Sta. as Journal Series No. 444.

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[3]Weeds of the North Central States, North Central Regional Publication No. 36, Univ. of Illinois Agr. Exp. Sta.

Rogers (7) reported that crops in general do not have much effect upon Russian knapweed. The weed was introduced from seed in Turkestan alfalfa and it was able to become established in the alfalfa, and to invade native grass sods. He states that smother crops should be tall and have the capacity to make a quick, dense growth and be persistent enough to hold their own against the weed. Cane or millet, sowed heavily in April or May, were suggested. Perennial crops must emerge early in the spring and make a rapid and dense growth during May, June and July and retain their vigor until frost. He suggests that a season of cultivation, followed by a seeding of alfalfa or a clover, is an effective method of eliminating the weed. Alfalfa has a disadvantage, however, in that it has a limited height.

Warren and Freed (10) state that perennial grass crops offer competition to Russian knapweed, but that these crops need heavy fertilization in order to insure good growth. Best results were obtained when the infested area was cultivated for at least 1 year prior to planting the crop. Grass crops were better adapted than legumes because they could be sprayed with 2,4-D.

Sodium chlorate applied at the rate of 4 to 6 pounds per square rod during late summer or fall, was effective in eliminating knapweed according to Warren and Freed (10), but 2,4-D was not effective. It killed the tops but regrowth occurred.

Several experiments had been conducted by the authors, which indicated that 2,4-D was equal or superior to 2,4,5-T, MCPA and several related chemicals. Results indicated that the ester forms were more readily absorbed than amine or sodium salt forms. Russian knapweed reacted to the chemical but appeared to be quite resistant. It appeared that the weed could be weakened with 2,4-D so that a crop could compete more effectively with it or that cultivation could kill it more readily.

Objectives of the study reported here were to determine ways to eliminate small infestations with chemicals, as well as ways to get rid of large infestations while crops adapted to South Dakota were being produced. It appeared that these objectives could be attained with the proper combination of crops, cultivation, and chemicals. If the area were cultivated when not occupied by a crop and if the weed were selectively sprayed in a crop tolerant to the herbicide, it appeared that several combinations might eliminate the weed in a few years.

Experimental Procedure and Results

Twelve acres of land heavily infested with Russian knapweed were leased during 1952 to study methods of eliminating this weed. Four general types of experiments were conducted: (1) a 3-year trial involving annual crops, cultivation, and 2,4-D; (2) a 4-year trial involving perennial forage crops, cultivation, and 2,4-D; (3) comparisons of soil sterilants applied at several dates and rates of application; and (4) 1-year tests in which new chemicals were screened for possible use in eliminating the weed. Soil sterilant treatments were applied on plots 9 by 15 feet, but all other plots were 1 rod by 3 rods.

The soil is an Eckman loam. The longtime average annual rainfall is 24 inches. However, only 13.6 were received in 1952, 14.3 (9.4 in June and July) in 1953, 25 in 1954, 15.8 in 1955 and 18.2 in 1956.

ANNUAL CROPS, CULTIVATION AND 2,4-D

A 3-year experiment involving the use of annual crops (winter rye, oats and sudangrass), intensive cultivation, and 2,4-D was initiated during the fall of 1952. A second experiment was initiated 1 year later. Spring applications of 2,4-D and spring cultivations were performed for the first experiment during 1953, but heavy rainfall prevented summer and late summer spraying or cultivation. Consequently, the first experiment was reinitiated and the two experiments handled as one, with 4 replications of 24 treatment combinations in a randomized block design. Weed stands were counted on the same 4 one-square-yard areas of each plot during late May each year. Final counts were made in 1957. Counts in 1952 were made before any treatments had been applied. Subsequent counts were made to evaluate the previous year's treatments. The treatments and the percentage of Russian knapweed killed are given in Table 1.

During the first fall, all plots were plowed. Plots receiving treatments 4 to 24 were seeded to winter rye at the rate of 2 bushels per acre.

First year. Plots receiving treatment 1 were cultivated every 2 weeks during the season (10 cultivations). Treatment 2 consisted

Table 1. Percentage of Russian knapweed eliminated with annual crops, cultivation and 2,4-D.

First fall treatment	First year		Second year		Third year	
	Treatment[a]	Kill	Treatment[a]	Kill	Treatment[a]	Kill
1. Plow...	Cult. 2 wks.	92	Cult.[b], rye	99	Cultivate	95
2. Plow...	Cult. 2 & 3 wks.	92	Cult.[b], rye	99	Cultivate	95
3. Plow...	Cult. 3 wks	92	Cult.[b], rye	99	Cultivate	95
4. Rye....	Cult., rye	40	Cult., rye	70	Cultivate	67
5. Rye....	Cult., rye	40	Cultivate	80	Cult., sudan	68
6. Rye....	1 lb cult., rye	71	Cultivate	74	Cult., sudan	72
7. Rye....	1 lb cult., rye	71	Cultivate	74	Oats, ½ lb	75
8. Rye....	1 lb cult., rye	71	1½ lb post	89	Cult., sudan	95
9. Rye....	1 lb cult., rye	71	1½ lb post	89	Oats, ½ lb	74
10. Rye....	1 lb cult.	71	Oats, 1 lb, cult.	90	Oats, ½ lb	91
11. Rye....	1½ lb post, rye	89	Cultivate	81	Cult., sudan	79
12. Rye....	1½ lb post, rye	89	Cultivate	81	Oats, ½ lb	60
13. Rye....	1½ lb post, rye	89	1½ lb post	89	Cult., sudan	94
14. Rye....	1½ lb post, rye	89	1½ lb post	89	Oats, ½ lb	79
15. Rye....	1½ lb post	89	Oats, 1 lb, cult	92	Oats, ½ lb	90
16. Rye....	1 lb & 1 lb, rye	90	Cultivate	70	Cult., sudan	76
17. Rye....	1 lb & 1 lb, rye	90	Cultivate	70	Oats, ½ lb	81
18. Rye....	1 lb & 1 lb, rye	90	1½ post	88	Oats, ½ lb	76
19. Rye....	1 lb & 1 lb	90	Oats, 1 lb, cult.	92	Oats, ½ lb, cult	93
20. Rye....	1 lb & 1½ lb, rye	91	Cultivate	94	Cult., sudan	89
21. Rye....	1 lb & 1½ lb, rye	91	Cultivate	94	Oats, ½ lb	81
22. Rye....	1 lb & 1½ lb, rye	91	1½ lb post	85	Cult., sudan	95
23. Rye....	1 lb & 1½ lb, rye	91	1½ lb post	85	Oats, ½ lb	84
24. Rye....	1 lb & 1½ lb	91	Oats, 1 lb, cult.	93	Oats, ½ lb, cult	95

[a]"lb" refers to amount of 2,4-D applied per acre; "post" to post harvest application of 2,4-D; "cult." to intensive cultivation.
[b]Cultivated at same interval as the previous year.

of cultivation at 2-week intervals prior to August 1 and at 3-week intervals after that date (9 operations). Treatment 3 was cultivated every 3 weeks (7 times) during the season. All cultivations were performed with a 7-foot field cultivator equipped with nine 12-inch sweeps that overlapped and all operations were performed at a depth of 4 inches. Cultivation started during late May and continued until late September. Each treatment eliminated 92 percent of the weed. In treatments 4 and 5, the rye crop was harvested and the stubble was plowed and cultivated twice before a second crop of rye was seeded. Forty percent of the knapweed was eliminated.

Treatments 6 to 10 were similar to treatments 4 and 5 except that they included a spring application of 1 lb/A acid equivalent, of an ethyl ester of 2,4-D shortly before the rye reached the boot stage of growth. Treatment 10 included an extra cultivation instead of the second rye crop. Seventy-one percent of the knapweed was eliminated, indicating that the spring application of 2,4-D was helpful in eliminating the weed.

Treatments 11 to 15 were similar to treatments 6 to 10 except that a 1½-pound application of 2,4-D was made in the stubble after harvest. This allowed time for post-harvest plowing, but no duckfooting before the second crop of rye was seeded. Treatment 15 included 1 cultivation, however, because rye was not seeded. Eighty-nine percent of the knapweed was eliminated, indicating that post-harvest spraying was more effective than spring spraying and extra cultivations.

Treatments 20 to 24 included a spring application of 1 pound of 2,4-D as in Treatments 6 to 10 and a post-harvest treatment of 1 ½ pounds as in Treatments 11 to 15. Treatments 16 to 19 were similar except that only 1 pound of 2,4-D was applied in the stubble. Neither combination was superior to a single fall application.

Second year. Intensive cultivation used in treatments 1 to 3 increased the percentage kill to 99 by September 1 and rye was seeded. The 3-week interval, which utilized 7 cultivations per year, was as effective as the other intervals with 9 or 10 operations.

Treatment 4 included harvesting the rye crop, post-harvest plowing and 2 cultivations before a third rye crop was seeded. The stand of knapweed was reduced an additional 30 percent. Treatments 5, 6, 7, 11, 12, 16, 17, 20 and 21 were similar to treatment 4 except that a third crop of rye was not seeded. In about half the treatments, the stand of knapweed was changed very little, but in the other half, the stand became thicker than it was at the end of the previous year.

Treatments 8, 9, 13, 14, 18, 22 and 23 substituted a 1½ pound application of 2,4-D in August and a fall plowing for the fall plowing and cultivation used in the majority of other treatments, and similar results were obtained. The stand of knapweed was reduced on some plots, but not on others.

Treatments 10, 15, 19 and 24 included seeding an oats crop which was sprayed with 1 pound of an ester when the grain was in the 5-leaf stage. The stubble was plowed and cultivated twice. In each case the

percentage reduction in stand of weeds was increased to 90 to 93 percent.

Third year. Rye in treatments 1 to 4 was harvested. The stubble was plowed and cultivated twice. The stand of knapweed increased slightly.

Nine of the treatments included three spring cultivations followed by a close-drilled crop of sudangrass which was harvested for forage in early September. The stubble was plowed. The treatment, when preceded by a fall application of 2,4-D, consistently increased the percentage elimination above 90 percent. Sudangrass that was not preceded by fall spraying did not increase the percentage elimination.

Eleven treatments included an oats crop that was sprayed with one-half pound of 2,4-D during the spring. In most cases the treatment failed to increase the percentage elimination beyond the point reached the previous year, and in almost half of the plots the stand increased.

Summary. Several combinations of cultivation, crop and 2,4-D were capable of reducing the stand 90 percent. However, the remaining 10 percent was difficult to kill.

Intensive cultivation eliminated over 90 percent of the knapweed in 1 year and 99 percent in 2 years, regardless of whether the operations were performed at 2- or 3-week intervals.

Two combinations involving the use of small grain reduced the stand more than 90 percent in 3 years. During the first year a crop of rye was sprayed with 1 pound acid equivalent of 2,4-D ester per acre. After harvest the stubble was sprayed with 1 pound of 2,4-D ester in one combination and 1½ pounds in the other, resulting in 90 to 91 percent kills. During the second and third years, a crop of oats was sprayed with 1 pound of 2,4-D ester per acre. After harvest the stubble was plowed and cultivated 3 times, resulting in a 2 percent stand reduction the second year and a 3 or 4 percent decrease the third. Without the aid of 2,4-D these crops could not compete favorably with the weed.

A fall application of 1½ lb/A acid equivalent of 2,4-D ester in grain stubble followed with fall plowing and 3 spring cultivations prior to seeding a crop of sudangrass was the treatment that most consistently reduced stands beyond 90 percent. The vigor of the remaining plants was reduced and 2.1 tons of hay per acre were produced. Without the fall spraying the stand of weeds was not reduced, remaining plants were vigorous and only 1.7 tons of hay were produced.

PERENNIAL CROPS, CULTIVATION, AND 2,4-D

A 3-year experiment was initiated in August 1952 which included 48 treatments involving perennial forage crops (alfalfa, bromegrass and crested wheatgrass), cultivation, and 2,4-D, replicated once in a randomized block design. Two treatments included alfalfa, 22 included bromegrass alone, 22 included crested wheatgrass and 2

utilized a mixture of alfalfa and one of the grasses. During the course of the experiment it was necessary to change the plans twice. Heavy rainfall in 1953 prevented cultivation during late July and August and spraying in September, causing the first alteration. The percentage of kill was so low on most plots at the end of 3 years that plans were altered a second time—all grass plots were sprayed again in May 1956. Weed counts were made on the same 4 one-square-yard areas of each plot during the late May 1952, 1955 and 1957 to determine original stand and to evaluate the treatments after 2 and 4 years. The altered treatments and percentage kill are given in Table 2.

Table 2. The mean percentage of Russian knapweed eliminated by the use of perennial crops, cultivation and 2,4-D.

First fall	First year treatment[a]	Second year			Third year treatment[a]	Fourth year[b] pct. kill	
		Treatment[a]	Pct. kill				
			B[c]	CW[c]		B[c]	CW[c]
1. Alfalfa.....	Alfalfa	Alfalfa	46	—	Alfalfa	48	—
2. Alf.–Grass..	Alf.–Grass	Alf.–Grass	64	48	Alf.–Grass	68	60
3. Grass.....	Grass	Grass	62	38	Grass	67	69
4. Plow.....	Cult., alfalfa	Alfalfa	48	—	Alfalfa	56	—
5. Plow.....	Cult., grass	Grass	48	38	Grass	71	76
6. Plow.....	Cult., grass	1½ lb May	78	72	Grass	92	87
7. Plow.....	Cult., grass	1½ lb June	80	76	Grass	95	92
8. Plow.....	Cult., grass	1½ lb Sept.	96	90	Grass	93	84
9. Plow.....	Cult., grass	1½ lb May & Sept.	92	90	Grass	91	90
10. Grass.....	1½ lb May	Grass	80	46	Grass	70	66
11. Grass.....	1½ lb June	Grass	74	34	Grass	90	62
12. Grass.....	———	Grass	76	67	Grass	69	67
13. Grass.....	1½ lb May	Grass	80	46	Grass	70	66
14. Grass.....	Grass	1½ lb May	62	48	Grass	65	56
15. Grass.....	Grass	1½ lb June	76	46	Grass	71	72
16. Grass.....	Grass	1½ lb Sept.	77	50	Grass	71	57
17. Grass.....	Grass	1½ lb May & Sept.	82	62	Grass	75	59
18. Grass.....	1½ lb May	1½ lb May	86	44	Grass	87	57
19. Grass.....	1½ lb June	1½ lb June	66	56	Grass	83	63
20. Grass.....	———	1½ lb Sept.	77	50	Grass	71	57
21. Grass.....	1½ lb May	1½ lb May & Sept.	82	72	Grass	81	69
22. Grass.....	1½ lb May	Grass	80	46	1½ lb May	75	57
23. Grass.....	1½ lb June	Grass	74	34	1½ lb June	71	61
24. Grass.....	———	Grass	76	67	1½ lb Sept.	70	65
25. Grass.....	1½ lb May	Grass	80	46	1½ lb May & Sept.	81	65

[a]"lb" refers to amount of 2,4–D applied per acre and "cult." to intensive cultivation.
[b]All treatments except 1, 2 and 4 included an additional 1½-pound application of 2,4–D during May of fourth year.
[c]B—Plots utilizing bromegrass, bromegrass in mixture with alfalfa or alfalfa alone; CW—Plots using crested wheatgrass alone or in mixture with alfalfa.

All plots were plowed during the third week of August 1952. Alfalfa was seeded alone in treatment 1 and in a mixture with either bromegrass or crested wheatgrass in treatment 2, while bromegrass or crested wheatgrass was seeded alone in treatments 3 and 10 to 25. Alfalfa was seeded at the rate of 8 lb/A and the grasses at the rate of 12 lb/A. One peck of oats per acre was seeded as a companion crop. The grasses were mixed with the oats and seeded with them. A top

dressing of 200 pounds of 16–20–0 fertilizer was disked into the plowing prior to seeding.

The first year, plots receiving treatments 4 to 9 were cultivated 4 times at 2-week intervals during late May, June and early July. They were cultivated once more during early September when crops were seeded in the same manner as was used the previous fall. Alfalfa was seeded in treatment 4 and brome or crested wheatgrass was seeded in treatments 5 to 9.

Treatments 6 to 9 included application of 1½ lb/A acid equivalent, of an ethyl ester of 2,4-D at different dates. The percentage elimination obtained in 2 years ranged from 72 to 96. There was little difference between the 2 grasses. September applications of 2,4-D reduced the stand 16 to 18 percent more than May or June treatments. Application of 2,4-D was repeated in 1956. Bromegrass plots gave 91 to 95 percent elimination and crested wheatgrass gave 84 to 92 percent elimination at the end of 4 years.

Alfalfa was seeded without prior cultivation the first fall in treatment 1 and after 5 cultivations the first year in treatment 4. The knapweed stand was reduced 46 and 48 percent in 2 years and 48 and 56 percent in 4 years by these 2 treatments. The cultivation in treatment 4 did not improve the treatment appreciably.

Treatments 3 and 5 were similar to treatments 1 and 4 except that bromegrass and crested wheatgrass were seeded instead of alfalfa. The cultivation used in treatment 5 did not cause it to be superior to treatment 3.

Treatment 2 included a seeding of an alfalfa-grass mixture without prior cultivation. The alfalfa-bromegrass mixture reduced the knapweed stand 64 percent in 2 years, which is better than alfalfa used alone in treatments 1 and 4, better than bromegrass used alone in treatment 5 and better than the alfalfa-crested wheatgrass mixture in treatment 2. The alfalfa-crested wheatgrass mixture reduced the stand 48 percent in 2 years, which is also better than crested wheatgrass used alone in treatments 3 and 5. During the last 2 years of the experiment, the alfalfa-bromegrass mixture in treatment 2 did not reduce the stand of knapweed, but the alfalfa-crested wheatgrass mixture reduced the stand slightly—an additional 12 percent. The two mixtures were equal to each other and they were superior to alfalfa used alone and about equal to either grass that had been sprayed during the fourth year.

In treatments 10, 11, 13, 18, 19, 21, 22, 23, and 25, 1½ lb/A of an ethyl ester of 2,4-D were applied during May or June the first year. One-third of the plots were retreated the second year but the retreatment did not reduce the stand appreciably. The percentage of weeds killed ranged from 66 to 86 percent in bromegrass plots and 34 to 72 percent in crested wheatgrass plots at the end of 2 years, indicating that bromegrass was a stronger competitor. Some plots were treated the third year and all were sprayed the fourth year, but the stand was not reduced appreciably in bromegrass plots. At the end of 4 years the percentage elimination in bromegrass plots ranged from 70 to 90 percent and in crested wheatgrass plots from 57 to 69

percent. Although bromegrass appeared to be somewhat more effective than crested wheatgrass for reducing knapweed stands, the difference was not as great at the end of 4 years as it was 2 years earlier.

Treatments 14 to 17 did not include a 2,4-D application during the first year but 1½ lb/A of an ethyl ester of 2,4-D were applied during the second. No 2,4-D was applied the third year, but a 1½-pound application was made the fourth. Treatment 24 included a similar 2,4-D application the third and fourth years and treatment 12 included a spraying the fourth year. All results were similar for treatments 10 to 25, indicating that the 2,4-D treatments were not very effective.

Summary. Bromegrass and crested wheatgrass, when aided by cultivation and 2,4-D application, were able to reduce Russian knapweed stands. Five cultivations prior to fall seeding one year and a fall application of 1½ pounds of 2,4-D ester the second year reduced the stand 90 to 96 percent. Subsequent applications of 2,4-D failed to reduce the stand further. Spring or summer applications of 2,4-D were less effective than a fall treatment, but subsequent treatments aided in attaining over 90 percent elimination in 4 years. They were not effective in reducing the Russian knapweed stand when either cultivation prior to seeding or 2,4-D application after the crop emerged was omitted from the combination of treatments.

Alfalfa was less effective. The knapweed emerged early, produced early rank growth and alfalfa did not grow tall enough to overshadow it. Five cultivations prior to a fall seeding of alfalfa or alfalfa-grass mixture did not weaken the knapweed sufficiently to allow the crop to gain the upper hand the following spring.

SOIL STERILANTS

Two experiments were conducted to determine the optimum rate of application of numerous soil sterilants for the elimination of small patches of Russian knapweed. In each experiment, the herbicides were applied on 2 dates—late July and mid-September. Shortly after treatment the plots were observed to determine the speed of action of each chemical. The following year the effects of the chemicals on the weed were noted. Each succeeding year, the plots were plowed and seeded to oats to determine the length of time that the chemicals would inhibit small grain production (Table 3).

Chemicals, rates of application required to eliminate 95 percent of the knapweed, and the years of residual effect are given in Table 3.

Chlorea, Ureabor, DB Granular, diuron, fenuron and erbon were tested in only one experiment as they were not available when the first one was conducted. All chemicals were more effective when applied during the fall. The lower rate was effective when applied in September, but the higher rate was sometimes needed for July applications. The highest rate of Ureabor used was 7½ pounds. This rate was effective in September but not in July. The substituted urea compounds were not effective when applied at a rate of one-half

Table 3. The minimum rate of soil sterilants required to eliminate 95 percent of Russian knapweed and years of residual effect.

Chemical	Lb per sq rd[a]	Residual effect (years)
Borax compounds		
Concentrated borascu[b]	10–15	3–5
Polybor[c]	10–15	3–5
Chlorates		
Sodium chlorate	5	2–4
Atlacide[d]	8	2–4
Borate–chlorate mixtures		
Chlorax[e]	8–10	3–5
Polybor–chlorate[f]	8–10	3–5
Borate–chlorate–monuron mixtures		
Chlorea[g]	5–7½	3+
Ureabor[h]	7½–?	3+
Borate–2,4–D mixture		
DB granular[i]	5–7	1–2
Ammonium sulfamate[j]	5–7	1
Substituted urea compounds		
Monuron	0.33[k]	6
Diuron	0.30[k]	4+
Fenuron	0.30[k]	4+
Erbon	½–1	2

[a]Amount of active ingredient for substituted ureas and erbon and amount of product for all others.
[b]Sodium borate ore, 61.5% boron trioxide.
[c]Disodium octoborate tetrahydrate 98% (64% boron trioxide).
[d]Sodium chlorate 58%.
[e]Sodium metaborate 58%, sodium chlorate 40%.
[f]Disodium octoborate tetrahydrate 73% (49% boron trioxide), sodium chlorate 25%.
[g]Sodium metaborate 54%, sodium chlorate 40%, monuron 1%.
[h]Disodium tetraborate pentahydrate 63.2%, disodium tetraborate decahydrate 30.8% (41.5% boron trioxide), monuron 4%.
[i]Disodium tetraborate pentahydrate 55% disodium tetraborate decahydrate 35.5% (39.2% boron trioxide), 2,4–D 7.5%.
[j]Ammonium sulfamate 80%.
[k]Did not give satisfactory weed control and had long residual effect.

pound active ingredient per square rod except for one experiment. Monuron had been applied in September 1952. Heavy rainfall in 1953 inundated the plots. When the water receded, the knapweed in monuron-treated plots was dead.

Other Chemicals

Numerous other chemicals were tested for their effect on Russian knapweed. One showed promise of being useful for controlling the weed.

An amine of 2,3,6-TBA (2,3,6-trichlorobenzoic acid) was applied to Russian knapweed that was 6 to 12 inches tall about May 20 in 2 experiments. Approximately 10 days later, the knapweed was plowed under and corn was planted. The corn was cultivated 3 times. Almost complete elimination of the weed was achieved with rates of 4 to 6 pounds acid equivalent per acre. In one test the corn emerged normally, but died within 2 weeks. In the other test and in 4 tests conducted on leafy spurge (2), corn was not damaged.

It is postulated that a lack of rainfall prior to plowing the first

experiment left the chemical on foliage and soil surface. When it was plowed, a concentrated layer of chemical was left on the plow sole. When corn roots reached the plow sole, the crop was killed. In the second experiment rainfall prior to plowing may have leached some chemical into the soil. Plowing did not leave a concentrated layer on the plow sole.

Amitrol (3-amino-1,2,4-triazole) at rates up to 8 lb/A active ingredient and silvex (2,4,5-trichloropropionic acid) at rates of 10 to 20 lb/A acid equivalent were used in the same manner as 2,3,6-TBA. Amitrol was not effective for eliminating the weed and silvex injured the corn at rates that were effective on the weed.

Amitrol at rates up to 12 pounds, 2,3,6-TBA at rates up to 6 pounds and silvex at rates up to 20 pounds per acre were ineffective when applied to knapweed growing in crested wheatgrass sod. Likewise, rates of 2 or 4 pounds of 2,4-D ester mixed with either 10 pounds Ammate (80% ammonium sulfamate), 20 pounds of TCA (trichloroacetic acid) acid equivalent or 5 pounds of endothal (3,6-endoxohexahydrophthalic acid) per acre failed to eliminate more than 30 to 40 percent of the knapweed treated in wheatgrass sod.

SUMMARY AND CONCLUSIONS

Two 3-year experiments utilizing 24 combinations of annual crops, cultivation and 2,4-D and one 4-year experiment using 48 combinations of perennial forage crops, cultivation and 2,4-D were conducted during 1952-1957. Each experiment was replicated in a randomized block design with plots 1 rod by 3 rods in size. Weed counts were made on 4 areas of 1 square yard in each plot during late May each year.

Two experiments comparing all commercially available soil sterilants at several rates on 2 dates of application were conducted in duplicate 9-foot by 15-foot (1/2 square rod) plots. The second experiment contained more chemicals as they became available. Data on speed of top kill and of residual activity as well as the effect on weeds were obtained.

Numerous chemicals were screened for possible use in the elimination of large infestations. Amitrol, 2,3,6-TBA and silvex were applied during the spring 10 days before plowing and planting corn. They and several mixtures of 2,4-D and either ammonium sulfamate, TCA, or endothal were also applied to Russian knapweed growing in grass sod.

The following conclusions can be drawn:

1. Russian knapweed reacts to 2,4-D but is relatively tolerant to it. Ester forms cause greater reaction than amine forms.

2. Several combinations of cultivation, crops and 2,4-D reduce Russian knapweed stands 85 to 90 percent, but the remaining 10 to 15 percent are difficult to kill.

3. Russian knapweed stands can be reduced 98 percent by 2 years of intensive cultivation. Operations need not be performed oftener than every 3 weeks if a duckfoot field cultivator is operated at a depth of 4 inches.

4. Three years of spraying in small grain and cultivating after harvest materially reduce the stand of Russian knapweed.

5. A season of intensive cultivation followed by a crop of bromegrass or crested wheatgrass that is sprayed with 2,4-D eliminates a high percentage of Russian knapweed. If either the cultivation or spraying is omitted, the grasses do not compete favorably with the weed.

6. A fall application of 2,4-D, a fall plowing, 3 spring cultivations and a close-drilled crop of sudangrass is one of few combinations that will reduce the stand of knapweed more than 90 percent. If the 2,4-D treatment or cultivation is omitted, the crop does not reduce the stand.

7. Alfalfa and alfalfa-grass mixtures do not compete favorably with Russian knapweed. Cultivation prior to seeding the crop does not give the crop enough advantage.

8. Several soil sterilants can be used to eliminate small patches of Russian knapweed.

9. TBA shows promise for use in eliminating large infestations of Russian knapweed. Rates with little residual effect are effective when their application is followed by plowing 10 days later.

10. Russian knapweed appears to be somewhat more difficult to eliminate than leafy spurge and considerably more difficult than field bindweed, Canada thistle or perennial sowthistle.

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Uncommon Plant Growth Regulators for the Control of Nutgrass and Oxalis[1]

DONALD P. GOWING and ROBERT W. LEEPER[2]

THE recognition of the herbicidal activity in the phenylacetic acids by Pybus et al. (2) is a matter of particular interest to those whose work is concerned with weed control in crops unusually sensitive to 2,4-D (2,4-dichlorophenoxyacetic acid) and its derivatives.

Many crops will be injured by 2,4-D applications at the rates used in weed control, but are not particularly damaged by the use of 2,4-D in a spray directed at weeds, and from which only incidental amounts of 2,4-D come into contact with the foliage of the crop. However, there are some crops, e.g., cotton, which are severely damaged by 2,4-D at rates far below those in common herbicidal use. The pineapple plant is of about the same order of sensitivity to 2,4-D, but in a different way. Although pineapple may not be greatly injured by a chance application of 2,4-D in drift amounts (say 2 to 5 grams per acre) the crop may be forced to flower out of season, and the fruits produced on the immature plants are then too small to meet the standard can size.

Although the formulation of the hormonal herbicide quite regularly spells the difference between success and failure in a commercial application, it has been our experience that an exceptionally wide range of 2,4-D and 2,4,5-T derivatives are ruled out of commercial use for weed control on pineapple plantations. Some 19 esters and other derivatives (alcohols, acetonitriles, acetamides, ethylsulfates, and the like) all have had more or less toxicty to nutgrass, but also have induced flowering in pineapples.

Work by Wain (3), and his colleagues, has shown that there are a number of crops which are not adversely affected by chlorinated phenoxy-*n*-alkyl acids with an even number (more than two) of carbons in the side chain, although weeds common in the fields may be killed by these compounds. For some plants, the explanation for this apparently lies in the ability of the sensitive plants to convert 4-(2,4-dichlorophenoxy)butyric acid, for example, to 2,4-D, which is then toxic.

Unfortunately, pineapple is forced to flower by 4-(2,4-dichlorophenoxy)butyric acid, although whether the compound is active in inducing flowering in its own right or only after beta-oxidation to 2,4-D may be debated. In any event, if growth regulators are to be used for weed control in the crop, some compound other than one containing the 2,4-D moiety must be used.

Two weeds of increasing importance in pineapple fields under Hawaiian conditions are nutgrass, *Cyperus rotundus*, and a bulb-

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forming oxalis, *Oxalis martiana*. It has been interesting to us that some chemicals which have high growth regulator activity in the Went split pea-stem test (1) also have some systemic activity on these weeds, and yet did not force pineapples to flower. Moreover, some of the materials with low or 0 split pea-stem test (which indicates a low order of growth regulator activity) have also been toxic to these weeds, though not systemic in their activity. Sometimes these materials, and the materials with high pea tests, were also toxic to the pineapple plant, but, since they did not force pineapples to flower, their use occasioned no more injury to the crop than would have been derived from a misdirected oil spray or other contact material.

MATERIALS AND METHODS

These investigations have covered a period of several years, and have involved treatment of established nutgrass or oxalis, *in situ*, on the islands of Oahu and Maui. The weeds were usually treated just prior to flowering. Chemicals have been dissolved in acetone or dimethylformamide, then added to water containing a wetting agent and triethanolamine or sodium bicarbonate to give the concentrations required for a final spray at 100 gal/A. Plots have been 5′ x 5′, replicated or not depending on the amount of chemical available. Usually, several rates of application have been used, the rates increasing by multiples of 2. Most of the growth regulators have been synthesized in the PRI laboratories by one of us (RWL) and materials from other sources are acknowledged below. The listing includes only compounds which have not induced flowering in pineapple.

Ratings of herbicidal effectiveness were made 3, 10, and 30 days after treatment. An oil spray (fortified with sodium pentachlorophenate) was used as a check on contact activity; oil-treated plots usually outgrew the contact injury by 10 days (nutgrass) or 30 days (oxalis). Compounds which reduced weed stand 40% or more, compared to the oil-treated controls, were rated "satisfactory".

RESULTS

Tables 1 and 2 show the results obtained. Of the materials tested at the rates shown, nine were toxic to nutgrass. Others might be toxic to nutgrass if tested at higher rates. The materials which were active in the split pea-stem test are growth-regulatory in nature and may have killed nutgrass by systemic activity (e.g., 2,5-dichlorophenoxyacetic acid, 2-methyl-5-chlorophenoxyacetic acid, and others). Those with a low or 0 pea test presumably killed by some contact or more limited systemic activity (e.g., 3-chloro-5-methylphenoxyacetic acid and 4-chlorophenylmercaptoacetic acid). However, it should be recognized that the pea plant exhibits some selectivity in its responses, and the pea test is not an infallible guide to growth regulator activity in other plants.

Table 1. Results of tests of substituted phenyl- and phenoxyacetic acids for toxicity to nutgrass and oxalis.

	Substituent[a]				Nutgrass		Oxalis		Pea test[c], %
	2	3	4	5	Rate, lb/A	Results[b]	Rate, lb/A	Results[b]	
a. *phenoxyacetic acids*	Br	Me			3,6	U			158
	Br		Me		3,6	U			81
		Br	Me		3,6	U			93
	Me			Br	3,6	U	0.25–2	S	137
	Br				0.25–2	U	0.25–2	S	83
		Me	Cl	Me	3,6	U			89
	Cl		Me		2,4	U			133
	Me	Cl			3,6	U			84
		Cl	Me		3,6	U			249
		Cl		Me	0.25–2	S	0.25–2	S	7
	Cl			Me	0.25–6	U	0.25–2	U	87
	Me			Cl	0.25–6	S	0.25–2	S	115
	Cl				0.25–2	U	0.25–2	S	62
		Cl			0.25–2	U	0.25–2	S	95
		Br		Br	2,4	U			0
	Cl	Cl			0.25–2	U	0.25–2	S	60
	Cl			Cl	0.25–2	S	0.25–2	S	57
	Me	Me			3,6	U			147
	Me			Me	0.2–1.5	U	0.2–1.5	U	113
		Me	Me		3,6	U			73
		Me		Me	0.25–2	U	0.25–2	S	0
		Eth			2,4	U			110
	isop			Me	0.25–2	U	0.25–2	S	39
	isop				0.25–2	U	0.25–2	U	0
	Me				0.25–6	U	0.25–2	U	42
		Me			0.25–2	U	0.25–2	U	24
			Me		0.25–6	S?			14
		NO_2			0.25–2	U	0.25–2	U	60
	Me		Me	Me	3,6	U			6
b. *phenylacetic acids*	Cl				0.25–2	U	0.25–2	S	111
		Cl			0.25–2	U	0.25–2	S	116
	Cl		Cl		3,6	U			150
		Cl	Cl		3,6	U			75
	Me	Me			3,6	U			185
	Me		Me		3,6	U			125
	Me			Me	0.25–6	S	0.25–2	U	98
		Me	Me		3,6	U			69
			OH		0.25–2	U	0.25–2	S	154
	Me				0.25–6	S	0.25–2	S	287
		Me			0.25–2	U	0.25–2	U	156
			Me		0.2–1.5	U	0.25–2	U	129

[a]Substituent: Br = bromo; Cl = chloro; Me = methyl; Eth = ethyl; isop = isopropyl; OH = hydroxy; NO_2 = nitro.
[b]Results: U = unsatisfactory or S = satisfactory (see text under Materials and Methods).
[c]Data of M. J. Kent of the PRI Chemistry Department; percent of activity of naphthaleneacetic acid at a concentration of 200 ppm.

In respect to the results with oxalis, 23 compounds showed some toxicity at the rates used. The toxic materials included those with both high and low pea tests. More of the 2,5-substituted materials had activity and more of the 3,5-substituted phenoxyacetic acids had some activity than was true on nutgrass. Neither of these combinations of substituents of alkyl or halogen groups has forced pineapple plants to flower thus far. Moreover, none of the phenylacetic, benzoic, or salicylic acids thus far tested (including a number not listed in Tables 1 and 2) have forced pineapple plants to flower at rates up to 2 lb/A. At 4 or 8 lb/A, trichlorobenzoic acid, in the DuPont "Trysben 200" formulation, has forced pineapples. Although listed as having given some toxicity to nutgrass, it is not regarded by the writers as really promising for this work.

Table 2. Results of tests of certain chemicals[a] for toxicity to nutgrass and oxalis.

	Nutgrass		Oxalis		Pea test[c], %
	Rate, lb/A	Results[b]	Rate, lb/A	Results[b]	
a. *benzoic and salicylic acids*					
2-chlorosalicylic acid	0.5–4	U	0.5–4	S	0
3,5-dibromosalicylic acid	0.5–4	U	0.5–4	S	0
2,4-dichlorobenzoic acid	2,10	U			0
3,5-dichlorosalicylic acid	0.5–4	U	0.5–4	S	0
pentachlorobenzoic acid	2,10	U			36
2,3,6-trichlorobenzoic acid	2–80	S			131
b. *miscellaneous growth regulators*					
4-chlorophenylmercaptoacetic acid	0.25–2	S	0.25–2	S	29
beta-(3-chlorophenyl)propionic acid	0.25–2	U	0.25–2	U	70
beta-(4-chlorophenyl)propionic acid	0.25–2	U	0.25–2	U	50
2,4-dichloro-alpha-cyanocinnamic acid	3,6	U			0
alpha-(2,4-dichlorophenoxy)valeric acid	0.25–2	U	0.25–2	S	68
alpha-(2,4-dimethylphenoxy)butyric acid	0.1–1	U	0.1–1	U	91
alpha-(3,5-dimethylphenoxy)butyric acid	0.25–2	U	0.25–2	U	18
alpha-(3,5-dimethylphenoxy)propionic acid	0.25–2	U	0.25–2	S	0
beta-(3,5-dimethylphenoxy)propionic acid	0.25–2	U	0.25–2	S	0
2,5-dimethylphenylmercaptoacetic acid	3,6	U			117
5-indanoxyacetic acid	0.25–2	U	0.25–2	U	113
beta-(indole-3)propionic acid	0.25–2	U	0.25–2	U	163
beta-(4-methylphenyl)propionic acid	0.25–2	U	0.25–2	U	73
2-naphthylacetic acid	0.2–1.5	U	0.2–1.5	U	107
4-phenanthreneacetic acid	0.25–2	U	0.25–2	S	69
phenylmercaptoacetic acid	0.5–4	U	0.5–4	S	66

[a]3-chlorosalicylic acid from Dow Chemical Co.; tri- and pentachlorobenzoic acid from Pennsalt Mfg. Co.; phenylmercaptoacetic acid and its 4-chloro-derivative from Evans Chemetics, Inc.; dichloro-alpha-cyanocinnamic acid from Chemagro Corp.; indolepropionic acid from Union Carbide Chem. Corp.

[b]Results: U = unsatisfactory or S = satisfactory (see text under Materials and Methods).

[c]Data of M. J. Kent of the PRI Chemistry Department; percent of activity of naphthaleneacetic acid at a concentration of 200 ppm.

DISCUSSION

It is considered that the importance of this work lies not in the prospect of immediate adaptation of the materials listed to commercial control of these weeds, but rather in pointing out systemic materials which may be of much narrower spectrum than 2,4-D herbicidally, but of particular interest owing to their high tolerance by the crop under consideration.

SUMMARY

A number of compounds were tested for toxicity to nutgrass, *Cyperus rotundus*, and a bulb-forming oxalis, *O. martiana*. Effective compounds included those with high and those with low activity in the split pea-stem test for growth regulator activity. As examples, the former group includes the 2,5-substituted phenoxyacetic acids and some phenylacetic acids; the latter group includes the 3,5-substituted phenoxyacetic acids.

The point is made that certain crops, like pineapple, have such an unusual sensitivity to the more efficient and broader-spectrum herbicides like 2,4-D, that some attention could well be paid to less effective materials because of their high tolerance by the crop.

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Chemical Fallow in the Southern Great Plains[1]

A. F. Wiese, J. J. Bond and T. J. Army[2]

The concept of reducing tillage operations with herbicides was first tested in California orchards in 1944 (9). In 1949, Johnston and Sullivan (7) gave a detailed discussion of chemicals and equipment needed for eliminating tillage in orchards. Over a 4-year period chemical weed control proved cheaper than cultural methods. Soil condition and water penetration were improved and soil erosion was reduced by chemical weed control.

In the Great Plains area, where residue conservation is needed to control wind erosion, eliminating mechanical tillage operations with herbicides has enormous potential. Recognizing this, T. S. Aasheim started experiments with chemical fallow, i.e. weed control with herbicides during the fallow period in 1948 at the North Montana Branch Station, Havre, Montana. These tests were expanded to 3 locations in Montana and the results were reported by Baker et al. (2) in 1956. They concluded that where chemical fallow controlled weeds, grain yields were comparable to yields from conventional tillage. Reduced yields occurred if chemical residues remained in the soil at planting time.

Krall (8) recently noted increased protein content of wheat after using 3-*p*(chlorophenyl)-1,1-dimethyl urea (monuron) for weed control during the fallow period.

Many studies have been conducted to find suitable herbicides for chemical fallow (3, 10, 11, 12, 13). These studies indicate that 2,4-D (2,4–dichlorophenoxyacetic acid) successfully controls broadleaf weeds. However, chemical control of annual grasses or volunteer wheat is often unsatisfactory. Good control of foxtail (*Setaria* sp.), witchgrass (*Panicum capillare*), downy brome (*Bromus tectorum*), and hairy chess (*Bromus comutatus*) was usually obtained. Stinkgrass (*Eragrostis cilianensis*) was not controlled with chemicals. Shafer (14) applied 3-amino-1,2,4-triazole (amitrol) and the sodium salt of 2,2-dichloropropionic acid (dalapon) with an airplane and observed that a minimum of 5 gallons of carrier per acre was required to obtain control of volunteer wheat and downy brome.

In preliminary studies in Wyoming, Barnes et al. (5) observed that water intake rates were higher on chemically fallowed plots than on plowed ground where only a sweepmachine was used. During the second 30 minutes of an hour run, chemically fallowed plots absorbed 0.95 inch of water; an increase of 216% and 250% over plowed ground and subsurface-tilled plots, respectively. Further studies on fallowed land in Wyoming showed that a chiseling operation in conjuction with chemical fallow gave maximum moisture intake rates (1, 6). Three or four years of fallow with chemicals alone

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created a soil condition that reduced moisture absorption (6). Baker (4) found that after a two-month fallow period, soil moisture was higher on the chemically fallowed plots than on conventional tillage plots. This difference occurred principally in the first foot. In a study where runoff was eliminated, Wiese and Army (16) found that during a 10-month fallow period total moisture storage and moisture distribution in the soil profile was not affected by fallowing with a disk, subsurface tillage equipment, or with chemical weed control.

In view of the need for improved residue and moisture conservation practices in the Southern Great Plains, an extensive research program with chemical fallow methods has been conducted since 1955 at the Southwestern Great Plains Field Station, Bushland, Texas. Studies were designed to evaluate herbicides for chemical fallow and to determine the effect of chemical fallow on moisture storage, crop yields, and residue conservation.

METHODS

Herbicidal evaluation.

Studies to find suitable herbicides for control of annual weeds were conducted during fallow periods in 1955, 1956, and 1957. Plot size was 1 square rod and the tests were randomized blocks with three replications. Weed control effectiveness was determined by counting weeds in two square meter areas in each plot.

Chemical control of volunteer wheat and sorghum was attempted in 1956 with various chemicals in randomized block experiments with three replications. The plot size was one row of wheat or sorghum thirty feet long. Effectiveness of the chemicals was determined by estimating the percentage of wheat or sorghum plants killed. Herbicides used in these studies were: monuron; dalapon; propylene glycol butyl ether ester of 2,4-D; sodium salt of trichloroacetic acid (TCA); amitrol; 3-phenyl-1,1-dimethyl urea (fenuron); ethanol and isopropyl series amine formulation of 2,4-D; isopropyl *N*-(3-chlorophenyl)carbamate (CIPC); an emulsifiable formulation of polychlorobenzoic acid (PBA); and a diethanolamine salt of maleic hydrazide (MH).

Moisture storage and crop production.

Effects of chemical fallow on moisture storage and crop yields were evaluated in a wheat–sorghum–fallow rotation. Chemical weed control with no mechanical tillage was compared with two other treatments: 1. chemical weed control during the fallow period with seed bed preparation just prior to seeding with 30 inch sweeps and 2. subsurface tillage with 30 inch sweeps. Two seeding methods were used on each fallow treatment. Conventional seeding methods, where much of the surface residue is covered during the seeding operation, were compared with a seeding technique resulting in a minimum of residue disturbance. The conventional seeding equipment used was a deep furrow-shovel-type drill for wheat and a lister planter for sorghum. The seed furrow openers used for minimum residue disturbance were custom built narrow coulter type openers. Plots

were 26⅔ by 270 feet. Treatments were replicated three times. Grain yields were determined by combine-harvesting a representative area of each plot. Moisture content at planting was determined by taking four cores per plot with a Veihmeyer tube to a depth of 6 feet. Chemical control of grass weeds during fallow periods was attempted with 6 pounds of dalapon or 4 pounds of amitrol per acre. Amitrol, which has little residual effect, was used when weed control was necessary immediately prior to planting a crop. Broadleaved weeds were controlled with ½ or 1 pound of an ester formulation of 2,4-D.

The soil type was Pullman silty clay loam. Average annual rainfall at the experiment station is 18.10 inches. The rainfall for 1955, 1956, 1957 and 1958 was 13.71, 13.29, 22.45 and 21.78 inches, respectively.

RESULTS AND DISCUSSION

Herbicidal evaluation.

An ester formulation of 2,4-D applied at 1 lb/A was the only herbicide that satisfactorily controlled Russian thistle (*Salsola pestifer*), kochia (*Kochia scoparia*), and puncture vine (*Tribulus terrestris*) (Table 1.). Dalapon, TCA, amitrol, monuron or fenuron applied to the foliage did not control stink grass (*Eragrostis cilianensis*) and witch grass (*Panuncum capillare*). Applications of herbicides after a tillage operation (pre-emergence) were not successful.

Table 1. Effect of herbicides and tillage on weeds.

Treatment	Pounds per acre	Plants per square meter in					
		1955[a]		1956[b]		1957[c]	
		Grasses	Broad-leaf	Grasses	Broad-leaf	Grasses	Broad-leaf
Foliage application							
Dalapon + 2,4–D ester	5+1	6.3	0.0	36.3	2.0	26.7	0.7
Dalapon + 2,4–D ester	10+1	4.9	0.2	24.3	1.2	14.0	1.3
TCA + 2,4–D ester	5+1	5.9	0.2	—	—	—	—
TCA + 2,4–D ester	10+1	4.2	0.0	—	—	—	—
Amitrol	4	—[d]	—	152.7	9.8	—	—
Amitrol	6	—	—	161.5	7.0	—	—
Amitrol + 2,4–D ester	4+1	—	—	—	—	8.7	1.7
Amitrol + 2,4–D ester	6+1	—	—	—	—	6.7	2.0
Monuron + 2,4–D ester	2+1	11.5	0.0	—	—	—	—
Monuron + 2,4–D ester	4+1	11.8	0.0	—	—	—	—
Fenuron	2	—	—	83.4	74.2	—	—
Fenuron	4	—	—	26.3	43.3	—	—
Pre-emergence application							
2,4–D amine	4	—	—	7.8	0.0	6.7	0.0
2,4–D ester	4	—	—	—	—	6.3	2.0
2,4–D ester + CIPC	2+2	—	—	—	—	8.6	0.7
2,4–D ester + TCA	2+2	—	—	—	—	8.3	3.7
2,4–D ester + PBA	2+2	—	—	—	—	6.0	0.0
Normal tillage		0.2	0.0	0.2	0.0	—	—
Untreated		1.7	23.7	19.3	149.3	20.0	3.0
L.S.D. .05		6.4	—	38.8	53.5	9.3	NS

[a]Plots treated on June 6, 1955 and data obtained on August 5, 1955.
[b]Plots treated on June 12, 1956 and data obtained on August 8, 1956.
[c]Plots treated on June 5, 1957 and data obtained on July 4, 1957.
[d]No data available.

In many instances where broadleaved weeds were chemically controlled the grass poulation was increased (Table 1). The number of grass plants on chemically treated plots often exceeded the number on untreated plots; e.g., monuron plus 2,4-D ester in 1955; amitrol and fenuron in 1956. Broadleaved weeds such as Russian thistle and kochia are apparently more effective competitors than annual grasses. Grasses failed to develop when these broadleaved plants were allowed to grow.

Volunteer wheat was not satisfactorily controlled with herbicides under the dry conditions in 1956 (Table 2). The toxicity of 6 lb/A

Table 2. Wheat and sorghum kill with herbicides in 1956.

Herbicide	Pounds per acre	Carrier per acre	Percent wetting agent[a]	Percent kill in six weeks	
				Wheat	Sorghum
Dalapon	6	40 water	None	43	14
Dalapon	6	40 water	0.5	50	44
Dalapon	6	30 water, 10 oil	0.5	60	57
Dalapon	6	30 water, 10 oil	1.5	76	58
Dalapon	3+3	40 water	None	50	23
Amitrol	6	40 water	None	63	27
Amitrol	6	40 water	0.5	86	21
MH	6	40 water	None	33	97
MH	6	40 water	0.5	36	75
Dalapon + amitrol	6+1	40 water	None	—	23
Dalapon + amitrol	6+2	40 water	None	—	9
PBA	8	40 water	None	6	13
	L.S.D. .05			20	15

[a]Dynawet, Dow Chemical Company.

of dalapon to wheat and sorghum was increased by adding a wetting agent or applying the herbicide in an oil-water emulsion. Amitrol at 6 lb/A injured volunteer winter wheat but had little effect on volunteer sorghum. The toxicity of amitrol to wheat was increased by addition of a wetting agent. At 6 lb/A MH did not appreciably affect volunteer wheat but severely injured volunteer sorghum.

Moisture storage and crop production.

During the fallow periods in the wheat–sorghum–fallow rotation 2,4-D gave good control of broadleaved weeds if it was applied while the plants were young. Large plants were difficult to kill. Dalapon and amitrol did not consistently control grass-weeds or volunteer wheat and sorghum.

Chemical fallow generally resulted in less moisture storage during the fallow period than subsurface tillage (Tables 3 and 4). Reduction in soil moisture content with chemical fallow was particularly marked at wheat seeding time. As a result of the reduced moisture reserves at seeding, grain yields of wheat and sorghum were generally less with chemical fallow.

Due to dry weather in 1955 and hail in 1956, no wheat was harvested. Severe drought eliminated the sorghum crop in 1955.

Planting of wheat and sorghum was successful with both conven-

Table 3. Effect of weed control methods on available moisture content at seeding and wheat yields.

Weed control method	1957		1958	
	Inches moisture at seeding[a]	Wheat bu/A	Inches moisture at seeding[a]	Wheat bu/A
Sweep alone	2.01	7.7	7.20	24.3
Chemical plus mechanical seedbed preparation	.33	5.0	4.92	21.3
Chemical alone	.00	6.3	4.08	21.8
L.S.D. .05	1.47	1.1	1.98	2.1

[a]Acre inches of moisture above wilting point in the top 6 feet of soil.

Table 4. Effect of weed control methods on available moisture content at seeding and sorghum yields.

Weed control method	1956*	1957		1958	
	Sorghum lb/A	Inches moisture at seeding[a]	Sorghum lb/A	Inches moisture at seeding[a]	Sorghum lb/A
Sweep alone	1166	4.64	2465	5.82	2061
Chemical plus mechanical seedbed preparation	1090	3.44	2333	4.74	1666
Chemical alone	618	3.44	2057	5.34	2192
L.S.D. .05	172	NS	235	NS	307

*No moisture data were taken in 1956.
[a]Acre inches of moisture above wilting point in the top 6 feet of soil.

tional and minimum residue disturbance equipment. Planting method had no measurable effect on wheat and sorghum yields.

Field observation of the wheat–sorghum–fallow cropping system indicated that with chemical fallow considerably more wheat stubble remained on the surface over the winter period than with sweep tillage (Figure 1). Furthermore, a considerable portion of the wheat stubble on the chemically fallowed plots usually remained standing until the next sorghum crop was seeded. The standing stubble would reduce the hazard of wind erosion. Following sorghum, no weed control practices were necessary from harvest until weed growth began the following spring. Winter residue amounts, therefore, were not related to weed control treatments.

Studies over the Great Plains area indicate that chemical fallow may be feasible when chemicals become available which will control grass weeds. At the present time, 2,4-D successfully controls broadleaved weeds. Available data indicate that when adequate weed control is obtained with chemicals, moisture storage and crop yields can be expected to equal that obtained with present dryland tillage practices. The possibility of increasing moisture storage and yields with chemical fallow appears remote. However, increased residue conservation with chemical fallow decreases potential wind erodibility. This factor alone would make chemical fallow a highly desirable practice for dryland farming.

Figure 1. Comparison of chemical weed control (left) with sweep tillage (right). September 26,1956. Southwestern Great Plains Field Station, Bushland, Texas.

SUMMARY

Studies to evaluate herbicides for use in chemical fallow and to determine the effect of chemical fallow on moisture storage, crop yields, and residue conservation have been conducted since 1955. Satisfactory control of broadleaved weeds was obtained with 2,4-D. Grasses were not satisfactorily controlled with chemicals. More moisture was usually stored prior to seeding with sweep tillage than with chemical fallow. Decreased yields on chemically fallowed plots reflected this lower moisture storage. The wind erosion hazard, following wheat harvest, was reduced with chemical fallow.

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Pre-emergence Herbicides on Alfalfa and Birdsfoot Trefoil[1]

MARVIN M. SCHREIBER[2]

INTRODUCTION

THE first step in a satisfactory forage-legume program on the farm is the establishment of the legume. Success or failure here can mean the difference between a continued efficient rotation system and a financial loss. Many farmers have been reluctant to plow up old seedings at the proper time because of the cost of new seedings and the possibilities of seeding failures. Also, new seedings may appear successful in the seeding year only to be lost during the first winter. This paper is a report of 3 years' study at Ithaca, New York, on the use of herbicides applied pre-emergence to aid in the establishment of forage legumes without a companion grain crop.

Seeding failures have many causes, not the least of which is competition from companion crops or weed growth in the year of establishment. In most areas seeding with companion crops to reduce weed competition is common. This practice, however, was developed because other effective methods of reducing weed competition were unknown. Most farmers could ill afford to lose production in the year of establishment. Today, through the development of selective herbicides for the control of weeds in forage legumes, alternative methods of seedling establishment may be available to the farmer and often a hay crop may be produced in the seeding year.

REVIEW OF LITERATURE

Within the past few years several new pre-emergence herbicides have been suggested as possible materials for weed control in forage legumes. Neburon (1-*n*-butyl-3-(3,4-dichlorophenyl)-1-methylurea) was first introduced as a lawn and turf herbicide primarily for the control of crabgrass (*Digitaria* spp.) and chickweed (*Stellaria* spp.) (1, 6). It was not long, however, before its potential on forage legumes was investigated. Early work by Churchill (2) and Kerkin and Peters (8, 9) showed marked selectivity in alfalfa and birdsfoot trefoil from both pre-emergence and early post-emergence treatments. Kerkin and Peters (8), by the use of neburon at 1 to 4 lb/A, were able to more than triple the yield of alfalfa in the year of establishment by significantly reducing broadleaved weed competition. However, neburon has been reported to be ineffective against many common annual and perennial weedy grasses (7) and to have some limitation under dry soil conditions (12).

[1]Cooperative investigations between the Department of Agronomy, New York State College of Agr., Ithaca, New York and the Crops Research Division, A.R.S., U.S.D.A. as Agronomy Paper No. 469.

[2]Research Agronomist, Crops Research Division, A.R.S., U.S.D.A., Ithaca, New York. Present address: Department of Botany and Plant Pathology, Purdue Univ., Lafayette, Indiana.

EPTC (ethyl-di-*n*-propylthiolcarbamate), another recently developed herbicide, has given conflicting results as a pre-emergence herbicide on forage legumes. Elder (4) reports excellent control of weedy grasses and broadleaved weeds at 8 lb/A. Howden (6) and Dowler and Willard (3) report effective control of grasses only while Switzer (11) and Robinson and Dunham (10) report little or no control of either weedy grasses or broadleaved weeds.

MATERIALS AND METHODS

1957 A split-plot design experiment with three replications, with alfalfa and birdsfoot trefoil representing the whole-plot and treatments the split-plot, was initiated in the spring of 1957 on a silty clay loam at Ithaca, New York. The individual plots were 6 feet wide and 36 feet long. The area, previously in ryegrass sod, was plowed, fertilized with 200 lb/A of 0-20-20 fertilizer and disked to a fine seedbed. Narragansett alfalfa and Viking birdsfoot trefoil was seeded at 12 and 6 lb/A, respectively, on May 3, 1957, using a 6-foot cultipacker seeder. Neburon at 1, 2, and 4 lb/A; EPTC at 6, 12, and 24 lb/A, and CDEC (2-chloroallyldiethyldithiocarbamate) at 4½, 9 and 18 lb/A were applied in 30 gallons of water per acre on May 8 to a very dry soil. A total of over 3 inches of rain occurred 2 days after treatments and rain continued for 11 days.

Stands were counted on July 26 and general observations on weed control and crop injury were recorded through the season. Because of a severe infestation of quackgrass (*Agropyron repens*), which completely over-shadowed the herbicidal treatments, this experiment was discontinued September 1.

1958 Because of the abandonment of the 1957 seeding, a second experiment, utilizing a similar experimental design in an adjacent field in the same area, was established in the spring of 1958. Both Narragansett alfalfa and Viking birdsfoot trefoil were seeded on May 14, as described for 1957. Because of intermittent rain for 8 days following seeding, treatments of neburon at ½, 1, 2 and 4 lb/A and EPTC at 1, 2, 4 and 8 lb/A were not made until May 23. Neither the weeds nor the legumes had emerged at the time of treatment.

Weeds and legumes were counted June 30 and general observations on growth and development were recorded during the entire growing season. On August 8 the botanical composition on all plots was studied by hand separation. The following day all plots were harvested for dry-weight yield determinations. Both legumes were in the ⅓- to ½-bloom stage at this time.

The neburon-treated and check-plots of alfalfa were sampled for detailed measurements on September 11. All alfalfa plants were removed from a 2 square-foot area in each plot and washed. The following measurements were made on each plant in each plot: number of shoots per plant, root diameter 2 centimeters below crown, crown diameter, dry weight of roots and dry weight of shoots. Birdsfoot trefoil from the neburon plots was not sampled because of the severe stand reduction at the high rates.

1959 Detailed measurements of the 1958 seeding were made on birdsfoot trefoil on May 8, and on alfalfa and birdsfoot trefoil on August 3, 1959. Botanical composition by hand separation was made on the first cut yield on June 6, and the second cut yield, mostly legume, was harvested August 20, 1959.

RESULTS AND DISCUSSION

In 1957 neburon gave effective annual weed control through June and July and EPTC and CDEC controlled annual weeds except mustard *(Brassica kaber)*. The predominant annual weeds in the untreated plots were lambs-quarters (*Chenopodium album*), pigweed (*Amaranthus retroflexus*) and smartweed (*Polygonum pesicaria*). Neburon looked superior to all other materials regardless of rate of application. None of the materials except EPTC at the high rate suppressed the dominant weedy grass, quackgrass.

Alfalfa was not injured by any of the herbicides. Birdsfoot trefoil, however, showed a definite susceptibility to neburon above 1 lb/A. The stands of crop plants and weeds taken on July 26, 1957 are shown in Table 1. As the rate of neburon increased from 1 to 4 lb/A the stand of birdsfoot trefoil was reduced accordingly.

Table 1. Pre-emergence herbicides on stands of legumes and weeds, June 26, 1957, based on 3 replications.

Herbicides and rate lb/A	Plants per sq ft of					
	Legumes		Broadleaved weeds in		Weedy grasses[a] in	
	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil
None	10	11	15	22	8	7
EPTC:						
6	15	6	5	13	6	4
12	10	7	4	6	6	4
24	15	13	2	4	2	1
Neburon:						
1	10	10	2	4	10	12
2	15	3	2	0	9	8
4	16	1	0	0	9	14
CDEC:						
4½	8	5	7	10	8	7
9	10	10	5	5	9	4
18	8	15	4	5	8	14

[a]Mostly quackgrass.

By late July a lack of residual action of all materials, particularly neburon, was evident. Only the 4 lb/A of neburon resulted in complete broadleaved weed control during the entire season.

The weed control in 1958 was similar to that in 1957 (Table 2). The annual weed population changed only slightly, but wild buckwheat (*Polygonum convolvulus*), ragweed (*Ambrosia artemisiifolia*) and volunteer buckwheat (*Fagopyron* spp.) were added. The primary weedy grass was yellow foxtail (*Setaria lutescens*).

Neburon even at the lowest rate of application was superior to EPTC in broadleaved weed and annual grass control. However, it became evident very early that neburon at 2 and 4 lb/A significantly

Table 2. Pre-emergence herbicides on the stands of legumes and weeds, June 30, 1958, based on 3 replications.

Herbicides and rate lb/A	Plants per sq ft of					
	Legumes		Broadleaved weeds in		Weedy grasses in	
	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil
None	24	14	10	22	7	24
EPTC:						
1	30	15	23	15	28	24
2	24	16	21	14	55	18
4	17	16	14	16	10	26
8	19	14	17	13	18	21
Neburon:						
½	26	17	3	7	5	11
1	21	15	2	3	13	10
2	26	15	3	2	6	13
4	24	5	3	1	1	1

reduced the stand of birdsfoot trefoil. Not only did neburon do an excellent job on broadleaved weeds, but at 2 and 4 lb/A it completely removed all volunteer buckwheat, as previously reported by Howden (6).

Neburon lacked residual action at the two lower rates of application in 1958, but lost effectiveness about a month later in 1958 than in 1957. Therefore, even in the 1 lb/A neburon plots alfalfa and birdsfoot trefoil plants had about 3 months of growth under greatly reduced weed competition.

The total dry-weight yields in the year of establishment are shown in Table 3. Although significant differences were found in treatment means and interactions between legume and treatment means they impart little information without a consideration of the quality of the total yield.

By comparing the yields of legume with the total yields (Table 3) it can be seen that 85 to 95 percent of the total yield from the neburon-treated plots was pure alfalfa while from the EPTC-treated

Table 3. Pre-emergence herbicides on yields of legumes and weeds in the seeding year of alfalfa and birdsfoot trefoil, August 8, 1958, based on 3 replications.

Herbicides and rate lb/A	Tons of dry matter per acre of							
	Legumes		Broadleaved weeds		Weedy grasses		Total	
	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil
None	.85	.18	.76	1.31	.18	.26	1.79	1.75
EPTC:								
1	.49	.17	.42	1.46	.34	.16	1.25	1.78
2	.69	.24	.62	1.41	.27	.25	1.58	1.90
4	.64	.32	.56	.97	.18	.32	1.38	1.61
8	.58	.40	.39	1.10	.16	.29	1.13	1.79
Neburon:								
½	.96	.59	.48	.60	.13	.27	1.57	1.46
1	.89	.47	.05	.38	.12	.23	1.06	1.08
2	.93	.40	.02	.31	.10	.13	1.05	.84
4	1.06	.08	.01	.06	.04	.02	1.11	.16
LSD 5% level	.29		.51		.23		.42	

plots it was less than 50 percent alfalfa. Nearly 1 ton/A of high quality alfalfa was produced in the year of establishment by the use of neburon at 1, 2 or 4 lb/A. The lower rates of neburon significantly increased the dry-matter production of birdsfoot trefoil and significantly decreased the broadleaved weeds over that of the check.

No significant differences were found for the yield of alfalfa hay in the neburon treatments *versus* the untreated checks (Table 3) although significant differences existed in broadleaved weed control. Nevertheless, there were marked differences in the alfalfa plants that developed with and without severe weed competition. Weed competition in the establishment period of alfalfa significantly reduced the development of the individual alfalfa plants. The data presented in Table 4 show that as the neburon rate increased and thus decreased weed competition, the dry weight of alfalfa roots, root diameter, crown diameter, number and dry weight of shoots significantly increased. Also, there was a significant correlation ($r = .945$ to $.984$) between rate of neburon and each characteristic measured, except plants/sq. ft.

The values shown in Table 4 are mean values of three replications involving numerous individual plants. Though these values are important in themselves, Figures 1 to 3 graphically express the distribution of the individual plants in frequency classes for dry weight of roots, crown diameter and root diameter.

Table 4. Pre-emergence neburon on alfalfa plants in seeding year, September 11, 1958, based on 3 replications.

Neburon rate lb/A	Plants per sq ft	Shoots per plant	Dry weight of shoots gm	Dry weight of roots gm	Root diameter 2 cm below crown, mm	Crown diameter mm
0 (check)	16.0	3.6	.56	0.36	2.99	3.69
½	31.0	4.2	.65	.50	3.27	4.13
1	36.3	4.4	.63	.54	3.47	4.34
2	29.3	4.3	.82	.63	3.81	4.48
4	20.3	6.0	1.05	.82	4.13	5.23

The figures clearly indicate that a greater percentage of small plants existed in the check plots and that as neburon rates were increased, the percentage of larger plants increased; 64 percent of the alfalfa plants in the check plots had root weights of less than 0.40 gram, whereas in the 4 lb/A neburon plots only 19 percent had root weights less than 0.40 gram (Figure 1). The recent data of Gist and Mott (5) strongly suggest that alfalfa plants when exposed to high quantities of light in the earlier developmental stages will produce greater root development. Neburon, by removing almost all weed growth early in the establishment period, may have opened up the stand so that greater quantities of light were available to the alfalfa seedlings.

Although larger individual alfalfa plants will not insure winter survival under all conditions, under most winter conditions, the larger plants have a greater chance for survival. Although Kerkin

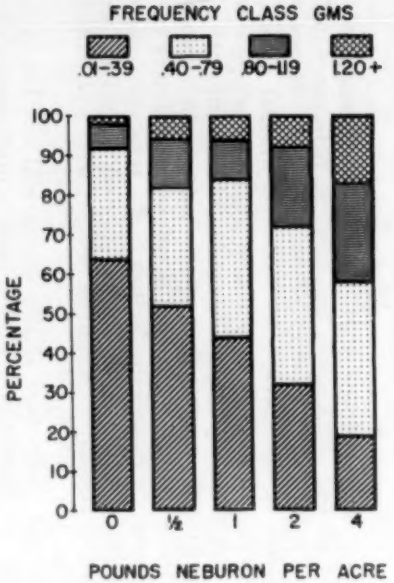

Figure 1. Percentage of alfalfa roots in dry-weight classes as influenced by weed control treatments, Values based on 3 replications.

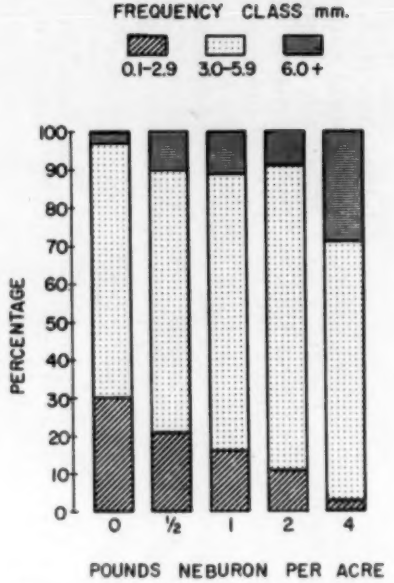

Figure 2. Percentage of alfalfa plants in various crown-diameter classes as affected by weed control treatments. Values based on 3 replications.

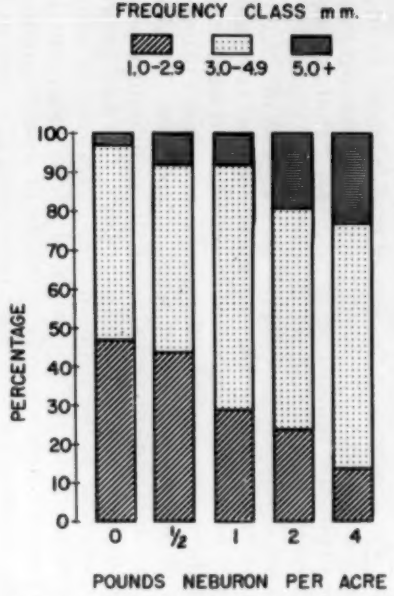

Figure 3. Percentage of alfalfa plants in various root-diameter classes as affected by weed control treatments. Values based on 3 replications.

and Peters did not measure root weights or crown and root diameters, they found that late-summer-seeded alfalfa plants that became established under weed-free conditions survived the first winter with much less heaving than those that developed under severe weed competition (9).

It is possible that root size has only an indirect effect on winter survival. In this experiment, the alfalfa plants in the neburon-treated plots showed significantly greater regrowth than the untreated check plots after the August 9 harvest, as measured by the number and dry weight of shoots (Table 4). Alfalfa plants that received 2 to 4 lb/A of neburon were 4 to 6 inches taller than those of the check on September 11, 1958. This additional growth should provide more reserve materials in the roots and catch more snow and thus give greater insulation to the soil and in turn reduce the freezing and thawing action, which causes heaving.

In the spring of 1959, the year following establishment, data were obtained which showed carry-over effects of the previous year's treatment (Table 5). The ½ and 1 lb/A rates of neburon significantly increased the dry weight of roots and number of shoots per plant without a change in the number of birdsfoot trefoil plants. However, by the end of the season this affect was undetectable in birdsfoot trefoil except at the highest rate of neburon (Table 6). Also, the significant correlation between rate of neburon and growth and development of alfalfa so striking in the year of establishment was non-existent by late summer of the following year except at the highest rate.

Although differences in legume development due to treatment did not exist at the end of the 1959 season, significant yield differ-

Table 5. Neburon treatment on birdsfoot trefoil one year after application May 8, 1959, based on 3 replications.

Neburon rate lb/A	Plants per sq ft	Dry weight of roots gm	Crown diameter mm	Shoots per plant
0	19	.28	5.2	8.9
½	14	.49	6.3	13.5
1	17	.65	6.3	14.3

Table 6. Neburon treatment on alfalfa and birdsfoot the year after application August 3, 1959, based on 3 replications.

Neburon rate lb/A	Plants per sq ft		Shoots per plant		Dry weight roots per plant gm		Dry weight shoots per plant gm		Crown diameter mm	
	A	BT	A	BT	A	BT	A	BT	A	BT
0	19	16	3.6	7.4	.85	.52	1.5	1.6	5.3	5.2
½	18	27	4.5	7.5	1.02	.44	2.5	1.5	6.0	5.1
1	26	18	3.7	8.3	1.06	.67	1.5	1.7	5.9	5.8
2	20	18	4.3	14.6	0.97	1.26	1.7	3.3	5.9	6.9
4	16	3	5.0	41.7	1.63	3.25	2.6	12.2	7.0	10.5

ences were found in the first cutting (Table 7) and in the total legume yield (first plus second cutting, Table 8) in 1959. The yield differences were greater with birdsfoot trefoil than in the alfalfa, thus suggesting that birdsfoot trefoil shows greater response to weed control than alfalfa.

Table 7. Pre-emergence herbicides on 1st cutting yields of legumes and weeds the year after application (June 27, 1959), based on 3 replications.

Herbicides and rate lb/A	Tons dry matter per acre of					
	Legumes		Broadleaved weeds		Weedy grasses	
	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil	Alfalfa	Birdsfoot trefoil
None	1.16	.83	.33	.45	.07	.37
EPTC						
1	1.22	.99	.17	.28	.19	.05
2	1.49	1.11	.18	.33	.04	.03
4	.93	1.02	.39	.39	.11	.05
8	1.25	1.07	.16	.41	.11	.01
Neburon						
½	1.51	1.52	.13	.14	.10	.08
1	1.33	1.34	.07	.10	.03	.07
2	1.42	1.41	.09	.02	.06	.07
4	1.54	1.09	0	.04	.08	.28
LSD 5%	.41		.23		.17	
1%	.56		.31		.23	

Table 8. Total legume yield the year after application (1959), based on 3 replications.

Herbicide and rate lb/A	Tons dry matter per acre	
	Alfalfa	Birdsfoot trefoil
None	2.44	2.11
EPTC		
1	2.68	2.31
2	3.00	2.44
4	2.36	2.43
8	2.71	2.51
Neburon		
½	2.96	2.96
1	2.60	2.72
2	2.74	2.71
4	2.96	2.16
LSD 5%	.44	
1%	.59	

CONCLUSIONS

1. Neburon, 1 to 4 lb/A applied pre-emergence, controlled the majority of common annual broadleaved weeds and weedy grasses in 1958 without injury to alfalfa.

2. With the use of an effective herbicide such as neburon and without the use of a companion crop, a yield of approximately 1 ton/A of pure alfalfa was produced in the seeding year.

3. The reduction in weed competition in the early stages of alfalfa establishment produced a greater percentage of more highly devel-

oped alfalfa plants on the basis of dry weight of roots, crown diameter, and root diameter. These highly developed alfalfa plants produced greater regrowth before overwintering.

4. Birdsfoot trefoil appeared to be extremely susceptible to rates of neburon above 1 lb/A but neburon may hold some promise at 1 lb/A as a pre-emergence herbicide in the establishment of birdsfoot trefoil.

5. Significant yield increases over the untreated checks were found in the year after treatment with neburon. Birdsfoot trefoil showed greater yield differences than alfalfa.

6. EPTC as a surface application at 8 lb/A in 1958 did not give satisfactory broadleaf or grass weed control but was non-injurious to both alfalfa and birdsfoot trefoil.

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News and Notes

The third meeting of the Weed Society of America was held at Denver, Colorado, February 22 to 25, 1960, as guests of the Western Weed Control Conference, with a registration of over 500. More than 150 papers were presented in 18 sessions, covering all types of weed control problems. The officers for 1960–61 are: President, K. P. Buchholtz, University of Wisconsin, Madison; Vice-President, Warren C. Shaw, U.S.D.A., Beltsville, Maryland; Secretary, F. W. Slife, University of Illinois, Urbana. The next meeting will be held at St. Louis, Missouri, Dec. 11 to 14, 1961, as guests of the North Central Weed Control Conference.

The Western Weed Control Conference was host to the Weed Society of America at Denver, February 22–25, and held no separate program. At the business meeting, the following officers were elected: President, W. R. Furtick, Oregon State College, Corvallis; Vice-President, Eugene Heikes, Montana State College, Bozeman; Secretary-Treasurer, E. J. Bowles, Room 353, Tioga Bldg., 2020 Milvia St., Berkeley, Calif. The next meeting of the Research Section of the WWCC will be held in Salt Lake City, March 21 and 22, 1961. The Research Progress Report for 1960 can be obtained from the Secretary for $2.00.

The next meeting of the North Central Weed Control Conference will be held at the Schroeder Hotel in Milwaukee, Wisconsin, December 12 to 15, 1960. The 1960 officers are: President, L. G. Holm, Department of Horticulture, University of Wisconsin, Madison 6; Vice-President, E. K. Alban, The Ohio State University, 1827 Neil Ave., Columbus 10, Ohio; Secretary-Treasurer, J. D. Furrer, Department of Agronomy, University of Nebraska, Lincoln, Nebraska. The 1959 meeting at Winnipeg, Manitoba, had almost 500 registrations. The 1959 Proceedings, which includes the printed Research Reports, can be obtained from the Secretary-Treasurer for $4.00.

The next meeting of the Southern Weed Conference will be at Hotel Soreno, St. Petersburg, Florida, January 18 to 20, 1961. Over 300 attended the 1960 meeting at Biloxi, Mississippi. The new officers are: President, R. A. Darrow, Texas A. & M. College, College Station; Vice-President, Walter K. Porter, Louisiana State University, Baton Rouge; and Secretary-Treasurer, R. E. Frans, University of Arkansas, Fayetteville. The 1960 Proceedings of the Southern Weed Conference can be obtained from Dr. Frans for $3.50.

The next meeting of the Northeastern Weed Control Conference will be held at the Hotel New Yorker, January 4, 5, and 6, 1961. The officers are: President, E. M. Rahn, Department of Horticulture, University of Delaware, Newark; Vice-President, Lawrence Southwick, Dow Chemical Co., Midland, Michigan. Secretary-Treasurer, D. A. Schallock, Department of Farm Crops, Rutgers University, New Brunswick, New Jersey. The Proceedings for 1960 can be obtained from the Secretary for $4.00, and the Supplement to the Proceedings for $2.00.

W. G. Westmoreland has resigned as Agronomy Extension Specialist (Weeds), North Carolina State College and accepted a position with Geigy Agricultural Chemicals, Sales Division. He will continue to live at Raleigh.

Dr. William F. Meggitt, until recently in the Department of Farm Crops, Rutgers University, New Jersey, is now Associate Professor of Farm Crops in Michigan State University, giving full time to weed research.

Dr. E. L. Knake has been appointed Assistant Professor of Field Crops Extension in the University of Illinois, specializing in weed control, effective February 1. Dr. Knake received the B.S. degree in 1949, M.S. in 1950, and Ph.D. in January, 1960, under Dr. F. W. Slife, all from the University of Illinios. From 1950–1956 he taught Vocational Agriculture.

Beginning February 1, Dr. F. W. Slife is spending a six months' sabbatical leave from the University of Illinois at the University of California, working under Dr. A. S. Crafts.

Mr. E. W. Stroube began work as Extension Specialist in Weed Control at The Ohio State University on April 1. Mr. Stroube received B.S. and M.S. degrees from the University of Kentucky, and expects to receive the Ph.D. degree from The Ohio State University soon.

Sustaining Members

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American Smelting & Refining Co., Plainfield, N. J.
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Naugatuck Chemical Division of United States Rubber Company, Bethany, Conn.
Niagara Chemical Division, Food Machinery & Chemical Corp., Middleport, N. Y.
Oberdorfer Foundries, Inc., Pump Division, Syracuse, N. Y.
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O. M. Scott & Sons Co., Marysville, Ohio
Spencer Chemical Co., Kansas City, Missouri
Spraying Systems Co., Bellwood, Illinois
Stauffer Chemical Co., New York, N. Y.
Swift & Co. Plant Food Division, Chicago, Illinois
Thompson-Hayward Chemical Co., Kansas City, New York
U. S. Borax Research Corp., Anaheim, Calif.
Velsicol Chemical Corp., Chicago, Illinois

BIBLIOGRAPHY OF WEED INVESTIGATIONS
for
July, August, September, 1959

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Prepared By

UNITED STATES DEPARTMENT OF AGRICULTURE

Agricultural Research Service
Crops Research Division
Weed Investigations Section

This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Crops Research Division, Agricultural Research Service, U.S.D.A. does not assume responsibility for the subject matter cited.

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